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The Upper Riphean Tangaur Subgroup of the Alatau Anticlinorium in the South Urals

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Abstract—Within the Alatau anticlinorium of the South Urals (the Zilim River middle course), structure and sedimentation settings of terrigenous and carbonate deposits of the Tangaur Subgroup of the Upper Riphean Karatau Group are investigated. Based on the analysis of 15 bed-by-bed described sections, siliciclastic and carbonate beds are correlated, and their lateral relations along and across the regional paleoslope are considered. It is established that the *Conophyton*-bearing strata at the base of the Min'yar Formation and overlying dolomite beds ranging up to the level with abundant *Minjaria* forms are most stable constituents of the Tangaur Subgroup. The Podinzer limestone beds are also easily traceable throughout the study region, but their facies affinity is laterally variable. A member of phytogenic limestones crowning the beds occurs only locally. Small erosion marks and desiccation cracks abundant in the beds imply a partial draining of the basin and existence of a major event boundary at that level. The intricate Inzer Formation that includes two carbonate and two terrigenous sequences is traceable only along the western periphery of the Bashkir meganticlinorium. East of the Zilim River middle courses, it is replaced by a siliciclastic succession. Main facies systems are reconstructed, and the basin evolution is characterized in terms of the event stratigraphy. The appearance level of cherts in the Min'yar Formation is shown to be diachronic. In general, the accumulation time of Tangaur Formation along the western periphery of the Bashkir meganticlinorium seems to be corresponding to the existence period of a large epicontinental sea basin that had a complex evolution.

Key words: Upper Riphean, South Urals, Karatau Group, Tangaur Subgroup, stratigraphy, correlation, sedimentation settings, sedimentation basin.

The Karatau Group of the Bashkir meganticlinorium, the Upper Riphean type unit in the unified regional stratigraphic scheme of the Urals and in the International stratigraphic scale, is divided into the Kipchak, Tangaur, and Kudash subgroups (Kozlov, 1989; Kozlov *et al.*, 1990; Semikhatov *et al.*, 1991, 1992; *Stratigraficheskie skhemy...*, 1993). The Kipchak Subgroup (Zilmerdak and Katav formations) corresponds to a major transgressive stage in development of the Late Riphean basin (Maslov, 1997a, 1997b), being composed of continental, near-shore, and subordinate coastal-shelf siliciclastic and carbonate facies. The Tangaur (Min'yar and Inzer formations) and Kudash (Uk and Krivaya Luka formations) subgroups are mostly composed of shallow-water, near-shore, and moderately deep-water sediments of an open shelf. Spatial and temporal relationships between these sediments reflect a succession of regressive–transgressive cycles in a sufficiently large pericratonic sea basin (Maslov, 1997a).

Most reliable isotopic dates are now available for the Tangaur Subgroup. Limestones from the lower part of the Inzer Formation (Podinzer Beds) are dated at 836 ± 25 Ma using the Pb–Pb isochron method (Ovchinnikova *et al.*, 1998). The isotopic age of authigenic illite from the Inzer Formation is 805–835 Ma and points to the time of burial diagenesis (Ovchinnikova *et al.*, 1995). The age of glauconite from sandstones of the lower Uk Subformation is determined to be 688 ± 10 Ma (K–Ar method), whereas the isochron age of Al-glauconite variety (Rb–Sr method) is 670 ± 10 Ma (Gorozhanin and Kutyavin, 1986).

In the Bashkir meganticlinorium, there are over 50 sections of the Tangaur Subgroup (Maslov and Krupenin, 1991; Maslov, 1976b), and about 20 of them are exposed in the middle courses of the Zilim River. However, most of these sections and sedimentological peculiarities of the subgroup remain unknown to many researchers. For this reason, the article is dedicated to detailed description of the Tangaur Subgroup and to analysis of lateral variations in composition and structure of its members and beds, which, combined with data on primary sedimentological properties of the rocks, elucidate some aspects in evolution of the middle Late Riphean sedimentation basin.

STRUCTURE OF THE TANGAUR SUBGROUP IN THE ZILIM RIVER MIDDLE COURSES

The study region represents a part of the so-called outer facies zone of the Bashkir meganticlinorium. In

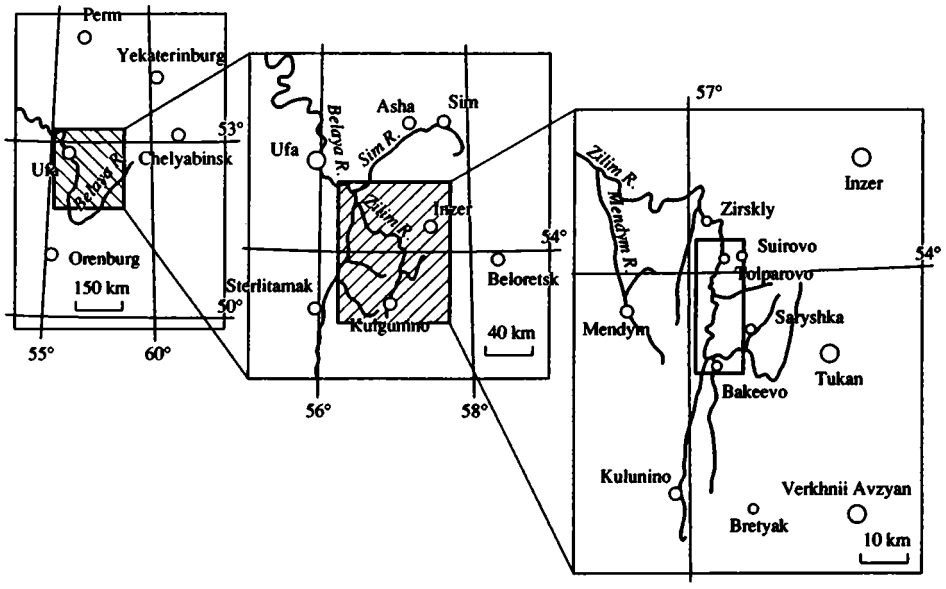

Fig. 1. Location of study areas.

the Zilim River middle (submeridional) course (Fig. 1), numerous sections of the Tangaur Subgroup are known at western limbs of the Zilim and Bakeevo synclines separated by the Zapadnokalinskii fault (Kozlov, 1986, 1986a). The rocks are exposed within two, western and eastern belts (Fig. 2). Characteristics of the Inzer and Min'yar formations, as well as descriptions of individual sections and enclosed stromatolites can be found in many publications (Raaben, 1975, 1981, 1985; Komar, 1978; Krylov, 1983; Raaben and Komar, 1983; *Stratotip rifeya...*, 1983; Maslov and Krupenin, 1991).

The Inzer Formation is subdivided in two subformations. The lower subformation (so-called Podinzer Beds) is predominantly composed of dark gray to black platy pelitomorphic and fine-grained limestones with columnar stromatolites in some sections. The Podinzer Beds rest conformably upon laminated microbial limestones of the Katav Formation. The upper Inzer Subformation includes two siliciclastic and a separating carbonate member observable in some sections of the western belt (Kozlov *et al.*, 1990; Maslov and Krupenin, 1991). Siliciclastic members are mostly composed of variegated and green-colored packets of alternating shales, sandstones, and siltstones with glauconite. The carbonate member consists of gray stromatolitic, microphytolithic, and detrital pelitomorphic to fine-grained limestones. In the eastern belt, this member is likely missing.

The Min'yar Formation comprises gray to light gray platy stromatolitic and detrital dolomites. Subordinate packets of shales, siltstones, and fine-grained sandstones occurring at several levels of the formation are several meters thick. Some of these packets at the base of the sequence with cherts are considered by some researchers as marking the boundary between the Minka and B'yanka subformations (Bekker, 1961; Bekker *et al.*, 1979; Kozlov, 1982, Kozlov *et al.*, 1990). Based on vertical distribution of stromatolites in the formation sections, the formation can be further subdivided into several characteristic beds (Raaben, 1983; Krylov, 1983; *Stratigraficheskii...*, 1994; and others). The base of the Min'yar Formation is universally marked by dolomite beds with stromatolites *Conophyton miloradovichi* var. *krylovi* Raab.

Within the *western belt*, southernmost exposures of the Min'yar Formation are observable in the left slope of the Zainysh Creek valley, where limestones of the Katav Formation are overlain by the following beds of the lower Inzer Subformation (Fig. 3, II).

(1) Isolated small outcrops of dark gray, medium- to thin-platy, obscurely bedded and/or massive pelitomorphic to fine-grained limestones; the thickness is about 140 m;

(2) Pelitomorphic to fine-grained laminated microbial (?) limestones; the thickness is about 100 m.

Higher, the rock debris (Member 3, approximate thickness 100–110 m) consists of green- and red-colored fine-grained sandstones likely belonging to the lower siliciclastic beds of the upper Inzer Subformation. Farther, after unexposed interval of about 130–140 m wide, there is a small outcrop of limestones with small-scale syncline- and wedge-like multidirectional bedding, which underlie microphytolithic limestones, their patterned varieties, and limestone breccias with flattened intraclasts. Above them, there are limestones with poorly preserved stromatolites. All these rocks are united into Member 5. After the next unexposed interval about 70 m wide with rare siltstone and shale fragments, the slope is covered by debris of fine-grained,

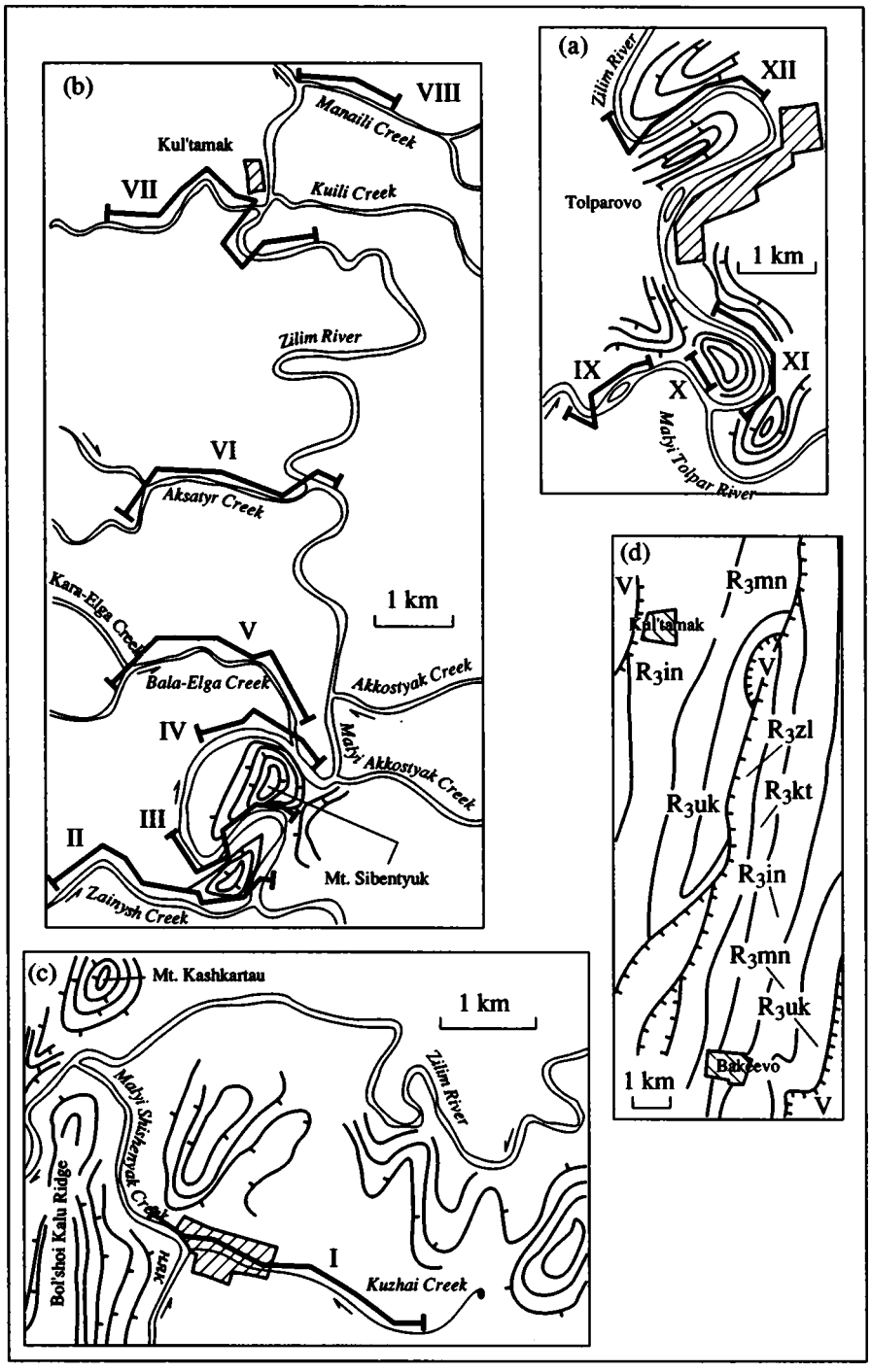

Fig. 2. Location of study sections (a–c) and schematic geological map of the Zilim River middle courses between the Bakeevo Village and former Kul'tamak Farm (d). Sections: (I) Kuzhai Creek near the Bakeevo Village, (II) Zainysh Creek, (III) left and right banks of the Zilim River near Mt. Sibentyuk, (IV) left bank of the Zilim River up- and downstream of the Bala-Elga Creek; (V) left bank of the Bala-Elga River; (VI) Aksatyr Creek and right bank of the Zilim River; (VII) Karamola Creek, left and right banks of the Zilim River; (VIII) Manaili Creek mouth; (IX) right and left banks of the Zilim River 1.0–1.5 km upstream of the Malyi Tolpar River mouth; (X) left slope of the Zilim River valley 0.5–0.7 km upstream of the Malyi Tolpar River mouth; (XI) right slope of the Zilim River valley downstream of the Malyi Tolpar River mouth; (XII) left and right slopes of the Zilim River valley downstream of the Tolparovo Village. Geological indices: (R_3zl) Zilmerdak, (R_3kt) Katav, (R_3in) Inzer, (R_3mn) Min'yar, and (R_3uk) Uk formations; (V) terrigenous sediments of the Vendian Asha Group.

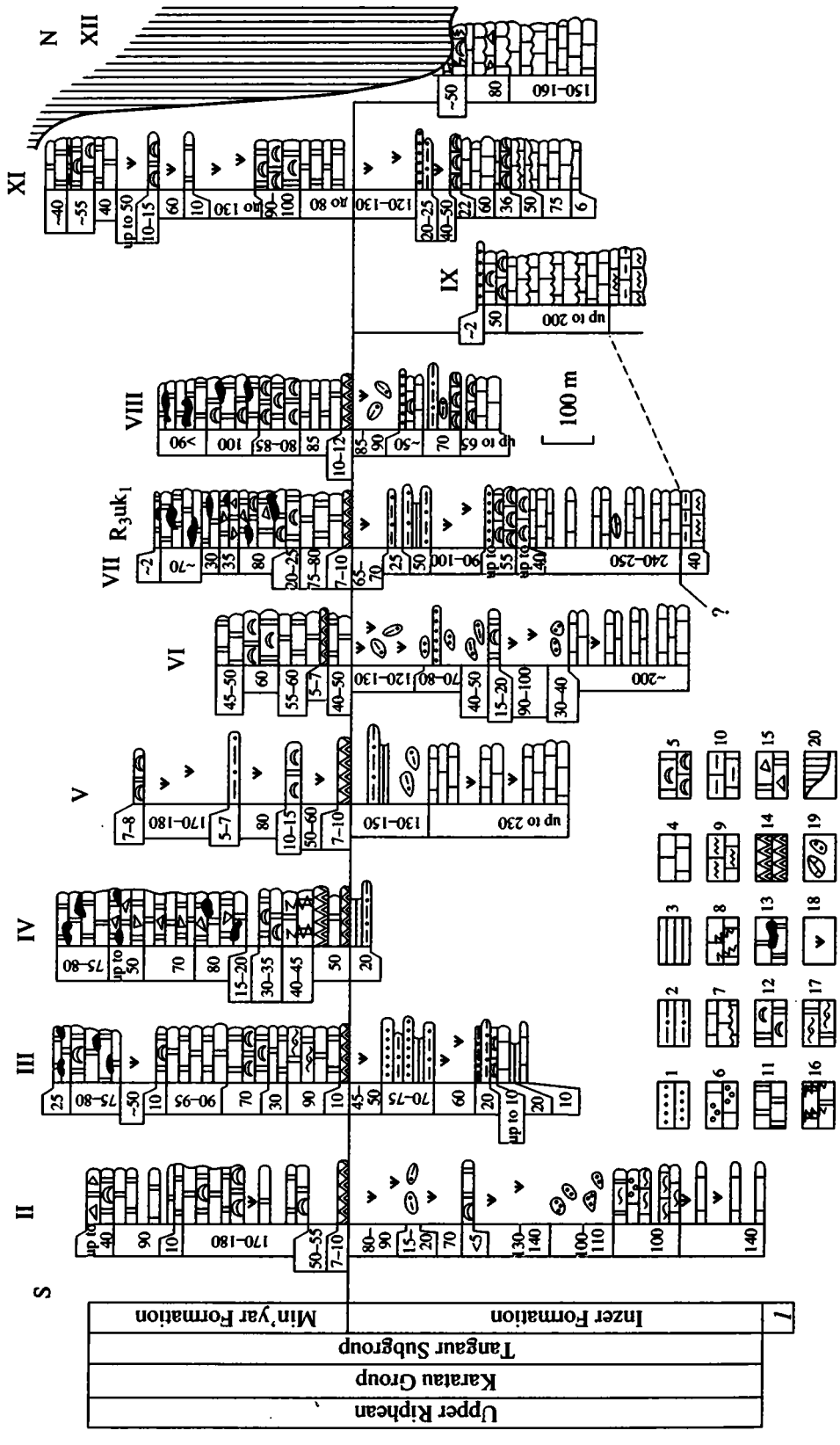

Fig. 3. Geologic columns of the Tangaur Subgroup in the western limb of the Zilim syncline. (1) sandstone; (2) siltstone; (3) shale; (4) limestone; (5) stromatolitic limestone; (6) microphytolithic limestone; (7) limestone with ripple marks and wavy lamination; (8) limestone with molar-tooth structures; (9) striate limestone; (10) clayey limestone; (11) dolomite; (12) stromatolitic dolomite; (13) dolomite with chert concretions; (15) synsedimentary dolomitic breccia with flat clasts; (16) dolomite with molar-tooth structures; (17) dolomite with cross wavy lamination; (18) unexposed interval; (19) rock composition in unexposed intervals; (20) pre-Early Vendian hiatus (column numbers correspond to section localities numbered in Fig. 2; in the scheme, the Katav Formation is indicated by number 1; in some columns, thickness of members is out of scale).

horizontally laminated, greenish to reddish gray sandstones and siltstones (Member 7, thickness 15–20 m). The abundance of debris indicates that corresponding beds occur *in situ* under thin cover of loose material. Taking into consideration position of carbonate Member 5 between two siliciclastic sequences, the lower of which is underlain by limestones of the Podinzer Beds and the upper one is overlain by dolomites with *Conophyton* remains, I assume that the member belongs to the middle part of the upper Inzer Subformation.

Min'yar Formation

(9) Medium- to thick-platy dolomites with poorly preserved *Conophyton* columns; the apparent thickness is 7–10 m.

(10) Unexposed interval 50–55 m wide.

(11) Gray thick-platy massive dolomites with poorly preserved stromatolites; the thickness is 170–180 m.

(12) Thin- to thick-platy dolomites with hummocky bedding surfaces; the thickness is 10 m.

(13). Horizontally laminated dolomites; the thickness is about 90 m.

In the right slope of the Zilim River valley near the mouth of the Zainysh Creek, there are exposed alternating thin- and thick-bedded dolomites with cherts (Member 14, thickness about 40 m). Dolomites enclose thin (5–15 cm) intraclastic beds occurring every 0.5–1.2 m and beaded stromatolitic bioherms up to 50–60 cm high and 2–3 m across.

In the left bank of the Zilim River southwest of the Mt. Sibentyuk, the following rock succession is observable (Fig. 3, III):

Upper Inzer Subformation

(1) Gray obscurely bedded medium-platy limestones with shale intercalations; the thickness is 10 m;

(2) Dark gray medium-platy limestones, mirophytolithic in the middle part; the thickness is 20 m;

(3) Limestones with *Gymnosolen* and *Parmites* bioherms separated by thin intraclastic interbeds; the thickness is 7–10 m;

(4) Pinkish gray platy siltstones with horizontal, cross, and wavy cross lamination; the thickness is 20 m. (Beds 3 and 4 are separated by the unexposed interval about 2 m wide).

The unexposed interval about 60 m wide is followed by outcrops of irregularly alternating variegated shales and siltstones (Member 6, thickness 70–75 m) with lenses of intraclastic and reddish gray limestones in the upper part of the member. Further, after the unexposed interval 45–50 m wide, the following rock succession is exposed:

Min'yar Formation

(8) Foliated dolomites with *Conophyton* remains; the thickness is 10 m;

(9) Medium- to thick-platy dolomites with thin horizontal and, in the uppermost part of the member, microbial lamination; the thickness is 90 m;

(10) Thin-platy dolomites with small-scale *Minjaria* bioherms; the thickness is 30 m;

(11) Gray flaggy obscurely bedded dolomites; the thickness is 15 m;

(12) Dolomites with *Minjaria* bioherms (0.4–0.6 m high and 1–1.2 across) irregularly alternating with medium-platy dolomites; the thickness is 35 m;

(13) Dark gray dolomites with *Minjaria* bioherms; the thickness is 20 m;

(14) Dark gray, obscurely bedded, flaggy dolomites; the thickness is about 90–95 m;

(15) Gray dolomites with *Minjaria* bioherms 0.4–0.7 m high and 1.2–1.4 m across; the thickness is 10 m;

(16) Unexposed interval about 50 m wide;

(17) Medium-platy dolomites with horizontal and microbial lamination; the thickness is 20 m;

(18) Medium-platy thin-bedded dolomites with intraclastic levels (0.1–0.15 m) occurring every 0.5–1.0 m and chert concretions; the thickness is 30 m;

(19) Light gray, medium- to thin-platy dolomites with chert concretions and rare stromatolitic bioherms; the thickness is 15–20 m;

(20) Gray thick-platy dolomites with columnar stromatolites; the thickness is 10 m;

(21) Gray medium-platy dolomites with chert concretions; the thickness is up to 25 m.

Comparison of the described Min'yar Formation section with concurrent interval of the Zainysh Creek section shows that some beds are well traceable. Par example, Bed 8 of dolomite with *Conophyton* remains corresponds to Bed 9 of the Zainysh Creek section. Platy dolomites of Bed 9 are correlative with Bed 10 of the latter, whereas overlying dolomites with *Minjaria* remains (beds 10–13) are similar to rocks of Bed 11 in the Zainysh Creek section. Thick-platy dolomites barren of stromatolites (Beds 14–16 in the section exposed southwest of Mt. Sibentyuk) can be correlated, more or less reliably, with compositionally and externally similar rocks of Beds 12 and 13 in the Zainysh Creek section, as well as with dolomites enclosing cherts, intraclasts, and stromatolites of Beds 17–21 and 14, respectively.

Northward, in the left slope of the Zilim River valley approximately 800–850 m upstream of the Bala-Elga Creek mouth (Fig. 3, IV), there are thin- and horizontally bedded pinkish and greenish gray siltstones and silty shales belonging to the uppermost Inzer Formation (Bed 1, thickness about 20 m). The latter are overlain, with a sharp boundary, by yellowish gray platy sandy dolomites with thin horizontal bedding and by dolo-

mites with *Colonella* remains and stromatolites *Conophyton miloradovichi*. These rocks are attributed to beds 2–4 about 50 m thick in total. They are overlain by the following rock succession.

(5) Gray and yellowish gray medium- to thick-platy dolomites with horizontal bedding and the molar-tooth structures at separate levels; the thickness is about 40–45 m.[1]

(6) Gray medium-platy dolomites with rare *Minjaria* bioherms; the thickness is 30–35 m;

(7) The unexposed interval 15–20 m wide;

(8) Gray to dark gray medium-platy dolomites with thin horizontal bedding, chert concretions, and abundant intraclasts occurring every 0.3–1.5 m in interbeds 7–15 cm thick; the thickness is 80 m;

(9) Intraclastic rocks with interbeds (10–25 cm) of dolomites characterized by horizontal and wavy lamination; the thickness is 70 m;

(10) Dark gray medium-platy dolomites with thin horizontal to microbial lamination and chert concretions; the thickness is up to 50 m;

(11) Gray medium-platy dolomites with chert concretions; the thickness is 75–80 m.

Comparison of the considered section with the previous one reveals several levels similar in composition and succession of rocks. For instance, beds 2–4 correspond to Bed 8 (dolomites with *Conophyton* remains) in the section at the southwestern piedmont of Mt. Sibentyuk; beds 5 is analogous to the beds 9 and 10, whereas dolomites with *Minjaria* remains (Bed 6) corresponds to beds 11–13. In the section exposed upstream of the Bala-Elga Creek, the overlying part of the Min'yar Formation encloses abundant intraclastic interbeds that is atypical of both the above-described and other synchronous sections in the Zilim River basin.

Approximately 750–1000 m northwards, only fragments of terrigenous and carbonate sections described above are exposed along the Bala-Elga Creek (Fig. 3, V). This area is characterized by the insignificant thickness of the upper Inzer Subformation; the carbonate member is likely missing or unexposed here.

Fragments of the upper parts of the Katav, Inzer, and Min'yar formations can be observed along the Aksatyr Creek flowing into the Zilim River 2.5 km north of the Bala-Elga Creek mouth (Fig, 3, VI). Two (lower and upper) siliciclastic and separating carbonate members of the upper Inzer Subformation are easily recognizable here.

The section of the Tangaur Subgroup crops out along the Karamola Creek and in latitudinal bend of the Zilim River upstream of the mentioned creek in the vicinity of the abandoned Kul'tamak Farm (Fig. 3, VII). The section of the Karamola Creek valley located 1.5 km upstream of its mouth is represented by rare outcrops of laminated limestones of the Katav Formation (Members 1 and 2, total thickness about 40 m). The Podinzer Beds exposed to the southeast are represented by dark gray medium- to thin-platy massive or obscurely banded limestones (Member 3, thickness about 240–250 m), by limestones with columnar stromatolites, and by thin-platy fine-grained limestones. These rocks are also traceable along the left bank of the Zilim River approximately 200–250 m upstream of the Karamola Creek mouth. Further, the following rock succession is exposed.

(6) Limestones with bioherms of nodular–columnar stromatolites and *Gymnosolen* buildups up to 0.5–0.7 m high and 1.5–2.0 m across; the thickness is 15–20 m;

(7) Gray to dark gray thin-platy pelitomorphic to fine-grained limestone; the thickness is 10 m;

(8) Limestones with columnar stromatolites; the thickness is about 20 m;

(9) Gray, thin to medium-platy fine-grained limestones; the thickness is 18 m;

(10) Limestones with columnar stromatolites; the thickness is 12–15 m.

The sequence of stromatolitic limestones up to 95 m thick is first distinguished in this section of the Podinzer Beds. Higher, the following rocks have been observed.

Upper Inzer Subformation

(11) Dark gray fine-grained medium-platy sandstones; the apparent thickness is 1.5–2.0 m;

(12) Unexposed interval 90–100 m wide;

(13) Brownish yellow coarse-grained siltstones with thin horizontal and gentle wavy lamination, enclosing thin packets of alternating siltstones and shales; the thickness is 50 m;

(14) Unexposed interval 20 m wide;

(15) Alternating coarse- to fine-grained siltstones; the thickness is up to 5 m;

(16) Unexposed interval 65–70 m wide.[2]

Min'yar Formation

(17) Dolomites with stromatolites *Conophyton miloradovichi*, which are overlain by dolomites (1.5–2.0 m thick) with microbial lamination; the thickness is 7–10 m;

(18) Gray medium-platy horizontally bedded dolomites, sugary varieties of which exhibit the fine feathery cross lamination; the thickness is 75–80 m;

(19) Massive and lumpy dolomites with poorly preserved stromatolites; the thickness is 20–25 m;

[1] The molar-tooth structures are formed in dolomites by the network of size- and shape-different fissures filled in with light gray fine- to medium-grained dolomitic material and oriented subparallel and/or subnormal to bedding.

[2] It seems that the carbonate sequence of the upper Inzer Subformation is unexposed here.

(20) Gray dolomites with obscure horizontal bedding, chert concretions, and poorly preserved stromatolites; the thickness is 80 m;

(21) Horizontally bedded dolomites with abundant intraclastic horizons 5–15 cm thick, occurring every 0.8–1.5 m; the thickness is 35 m;

(22) Gray medium-platy dolomites with cherts; the thickness is 30 m;

(23) Thick-platy massive or obscurely bedded dolomites with cherts; the thickness is about 70 m;

(24) Dolomites with stromatolites *Heterostylia zilimica* Raab. et Philatov; the thickness is about 2 m.

Bed 24 is overlain by siliciclastic rocks of the Uk Formation. This section is remarkable, spanning the complete range of the Min'yar Formation. It includes all characteristic rocks distinguishable in exposures along the Zainysh, Bala-Elga, and Aksatyr creeks, and in the vicinity of Mt. Sibentyuk. From the base upward, these are dolomites with *Conophyton* remains (Bed 17), platy dolomites (Bed 18), and flaggy to thin-platy dolomites with *Minjaria* (Bed 20). In composition and structure, higher levels of this section resemble the rock succession exposed along the Zilim River upstream of the Bala-Elga Creek mouth. The Min'yar Formation is crowned here by easily recognizable beds of medium- to thick-platy dolomites with cherts.

In the same area, another section of the Tangaur Subgroup is exposed in cliffs 30–40 m high along the right tributary of the Zilim River (Fig. 3, VIII).

Lower Inzer Subformation

(1) Gray thick-platy massive pelitomorphic to fine-grained limestones; the thickness is 5 m;

(2) Horizontally bedded limestones with interbeds of obliquely bedded varieties and, at some levels, with molar-tooth structures; the thickness is 10 m;

(3) Gray medium-platy fine-grained limestones; the thickness is 8 m;

(4) Yellowish gray, pelitomorphic porcelain-like limestones; the thickness is 3 m;

(5) Gray medium-platy obscurely bedded limestones; the thickness is 7 m;

(6) Light gray pelitomorphic porcelaneous limestones; the thickness is 2 m;

(7) Medium-platy, thin- horizontally bedded limestones with *Gymnosolen* remains; the thickness is 12 m;

(8) Unexposed interval 15 m wide;

(9) Thick-platy limestones with poorly preserved stromatolites; the thickness is 20 m;

(10) Unexposed interval 5 m wide;

(11) Light gay medium platy limestones with poorly preserved stromatolites and molar-tooth structures; the thickness is 4–5 m.

Upper Inzer Subformation

(12) Thin-platy siltstones (debris); the thickness is about 15–20 m;

(13) Brownish gray thin-platy siltstones; the thickness is 10 m;

(14) Unexposed interval 10 m wide, hosting debris of siltstones and shales;

(15) Gray medium-platy obscurely bedded limestones; the thickness is 30 m;

(16) Limestones with poorly preserved columnar stromatolites; the thickness is 12 m;

(17) Brownish gray thin-platy fine-grained sandstones; the thickness is 5–7 m;

(18) Unexposed interval 85–95 m wide with fragments of variegated siltstones and sandstones.

In this succession, beds 12 and 13 and the overlying unexposed interval represent the lower member, beds 15 and 16 the middle one, and Bed 17 together with next unexposed interval corresponds to the upper member of the upper Inzer Subformation.

Min'yar Formation

(19) Dolomites with *Conophyton* remains; the thickness is 10–12 m;

(20) Medium-platy horizontally and microbial-laminated dolomites; the thickness is 85 m;

(21) Thick-platy dolomites with poorly preserved columnar stromatolites; the thickness is 80–85 m;

(22) Medium to thin-platy massive and horizontally bedded dolomites with rare interbeds of columnar stromatolites; the thickness is up to 100 m;

(23) Medium- to thick-platy dolomites with chert concretions. The thickness is over 90 m.

At both slopes of the Zilim River valley along its sublatitudinal bend, approximately 3–4 km upstream of the Tolparovo Village, there is a series of picturesque vertical cliffs composed of cherry–red clayey and yellowish gray laminated limestones of the Katav Formation (Fig. 3, IX). In their upper parts, the cliffs enclose interbeds of black aphanitic limestones several dozens of centimeters thick and very similar to overlying dark gray thin- to medium-platy pelitomorphic and fine-gained limestones of the Podinzer Beds (units 2–4). The thickness of the Podinzer Beds proper is approximately 200 m here. Their most peculiar feature is presence of abundant and distinct symmetrical ripple marks of various types at the bedding planes. The upper part of the Podinzer Beds hosts an approximately 50-m-thick limestone Member 5 with dominant *Gymnosolen* remains accompanied in the topmost part by *Parmites* forms and small asperiomorphous bushy stromatolite (preliminary identification by V.N. Sergeev, 1999). This unit is well correlative with stromatolitic limestones from the upper part of the lower Inzer Subformation (Members 4–10) exposed in the Karamola Creek succession. Beds with stromatolite buildups 20–30 cm

Fig. 4. Phytogenic limestones from the upper part of the Podinzer Beds of the Inzer Formation with well-expressed desiccation cracks crossing stromatolite columns (locality X in Fig. 2, left bank of the Zilim River 1.0–1.2 km upstream of the Malyi Tolpar River mouth).

thick are commonly separated by thin laminae (1–2 cm) of ferruginate clayey limestones and/or marls (?). This feature implies breaks in carbonate material accumulation, whereas the low-amplitude ripple marks may suggest an intermittent subaerial exposition of sediments. Stromatolitic buildups of the Podinzer Beds are overlain with a sharp contact by brownish gray fine-grained sandstones with thin horizontal lamination (Member 6, thickness about 2 m). The surface of the limestone bed immediately under sandstones bears desiccation cracks (Fig. 4). The limestones themselves are intensely ferruginate, and tops of stromatolite columns are truncated along the distinct straight line.

Kozlov (1982) described the following succession of Podinzer Beds exposed along the left bank of the Zilim River upstream of the Tolparovo Village (Fig. 3, XI).

(1) Black and yellowish gray platy limestones; the thickness is 6 m;

(2) Gray to dark gray platy limestones; the thickness is 74 m;

(3) Platy irregularly bedded limestones; the thickness is 50 m;

(4) Limestones with stromatolites; the thickness is 13 m;

(5) Dark gray to light gray limestones; the thickness is 23 m;

(6) Gray limestones; the thickness is 60 m;

(7) Limestones with columnar stromatolites; the thickness is 22 m.

Bedding planes of limestone are decorated here with ripple marks as well. Upstream, in the right slope of the Zilim River valley, the unexposed interval 40–50 m wide is followed by exposures of thin-platy fine-grained sandstones and siltstones of the upper Inzer Subformation (Member 9, thickness 20–25 m). The section continues almost up to the Malyi Tolpar River mouth after the unexposed interval of about 120–130 m wide.

Min'yar Formation

(11) Gray medium-platy horizontally bedded dolomites; the thickness is 80 m;

(12) Thick-platy dolomites with large *Minjaria* bioherms separated by interbeds of thin-platy varieties; the thickness is about 90–100 m;

(13) Unexposed interval up to 130 m wide;

(14) Gray medium-platy horizontally bedded dolomites; the thickness is 10 m;

(15) Unexposed interval 60 m wide;

(16) Medium- to thick-platy dolomites, massive or with indistinct horizontal bedding; the thickness is 10–15 m;

(17) Unexposed interval up to 50 m wide;

(18) Thick-platy dolomites, massive or with obscure horizontal bedding; the thickness is 40 m;

(19) Thin-platy dolomitic siltstones and fine-grained sandstones irregularly alternating with thick-platy dolomites with *Gymnosolen* buildups; the thickness is about 55 m;[3]

(20) Gray medium-platy fine- to medium-grained dolomites with obscure bedding; the thickness is about 40 m.

Like all others, the above rock succession is very roughly subdivided. The internal structure of indicated beds is more intricate. Par example (see Fig. 5), the 11-m-thick interval of Bed 19 includes, in addition to dolomites with columnar stromatolites, the following rocks: thin-platy horizontally bedded fine- to medium-grained dolomites, dolomitic sandstones and siltstones,

[3] Dolomitic siltstones and sandstones here are rocks composed largely (over 50%) of silty and sandy dolomitic particles; in foreign publications they are termed dolsiltites and dolarenites, respectively.

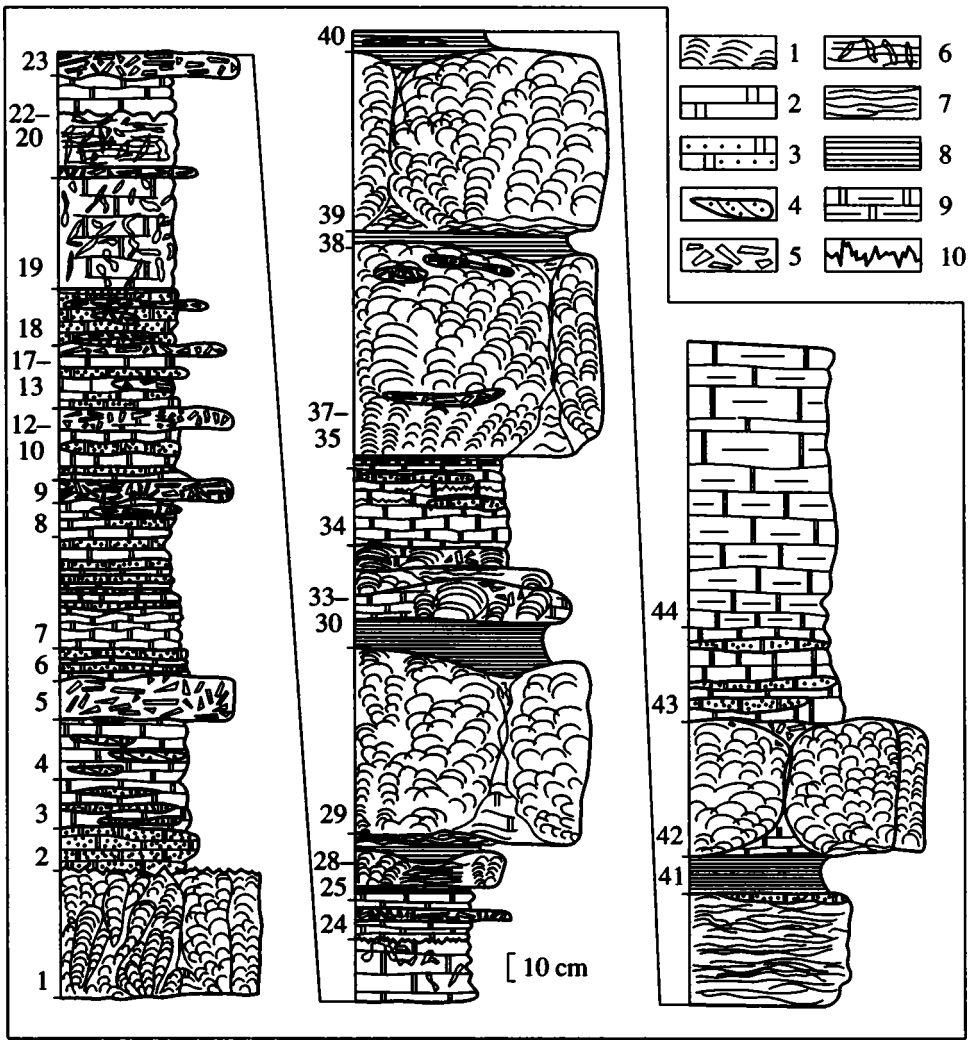

Fig. 5. Fine structure of the Bed part 19 (the Min'yar Formation) exposed along the right bank of the Zilim River slightly downstream of the Malyi Tolpar River mouth (locality XI in Fig. 2): (1) dolomite with columnar stromatolites; (2) fine- to medium-grained dolomites; (3) dolomitic sandstone; (4) dolomitic sandstone with gentle cross wavy lamination; (5) synsedimentary dolomitic breccia with flat clasts; (6) dolomite with molar-tooth structures; (7) dolomite with microbial lamination; (8) shale; (9) clayey dolomite; (10) stylolitic sutures (numbers denote particular beds of different lithology).

intraclastic varieties, dolomites with microbial lamination, clayey and carbonate–clayey dolomites, and dolomites with molar-tooth structures.

One more section of the Tangaur Subgroup is exposed at both sides of the Zilim River valley approximately 0.8–1.0 km downstream of the Tolparovo Village (Fig. 3, XII). In the left slope of the valley, there is well exposed transitional member between red-colored clayey limestones of the Katav Formation and gray limestones of the Podinzer Beds. Frequency of gray limestone beds in this member gradually increases upward, and gray rock varieties prevail over red-colored ones in the right slope of the valley. Three units of Podinzer Beds are recognizable here. The *lower* thickest (about 150–160 m) unit is composed of dark gray thin- to medium-platy massive and/or thin-bedded pelitomorphic to fine-grained limestones with prevailing even bedding planes. The upper part of the unit encloses an interlayer that exhibits a subparallel or local fan-like orientation of intraclasts. The *middle* unit (about 80 m) consists of dark thin-platy pelitomorphic limestones with intraclastic horizons up to 10–12 cm thick. Bedding planes reveal in this case abundant symmetrical ripple marks well exposed by weathering. In addition to the large-scale ripple marks with a distance between neighboring ridges of 5 to 7–8 cm, there are millimeter ripples covering the bedding plane areas of few decimeters across, which alternate with flat areas in a mosaic manner. In the transverse section, ripples usually exhibit the distinct wavy lamination emphasized by fine films of clayey and clayey–carbonate material. It is remarkable that limestone remains invariable in granulometric aspect below and above the films, which seem to be solely responsible for preservation of ripple marks

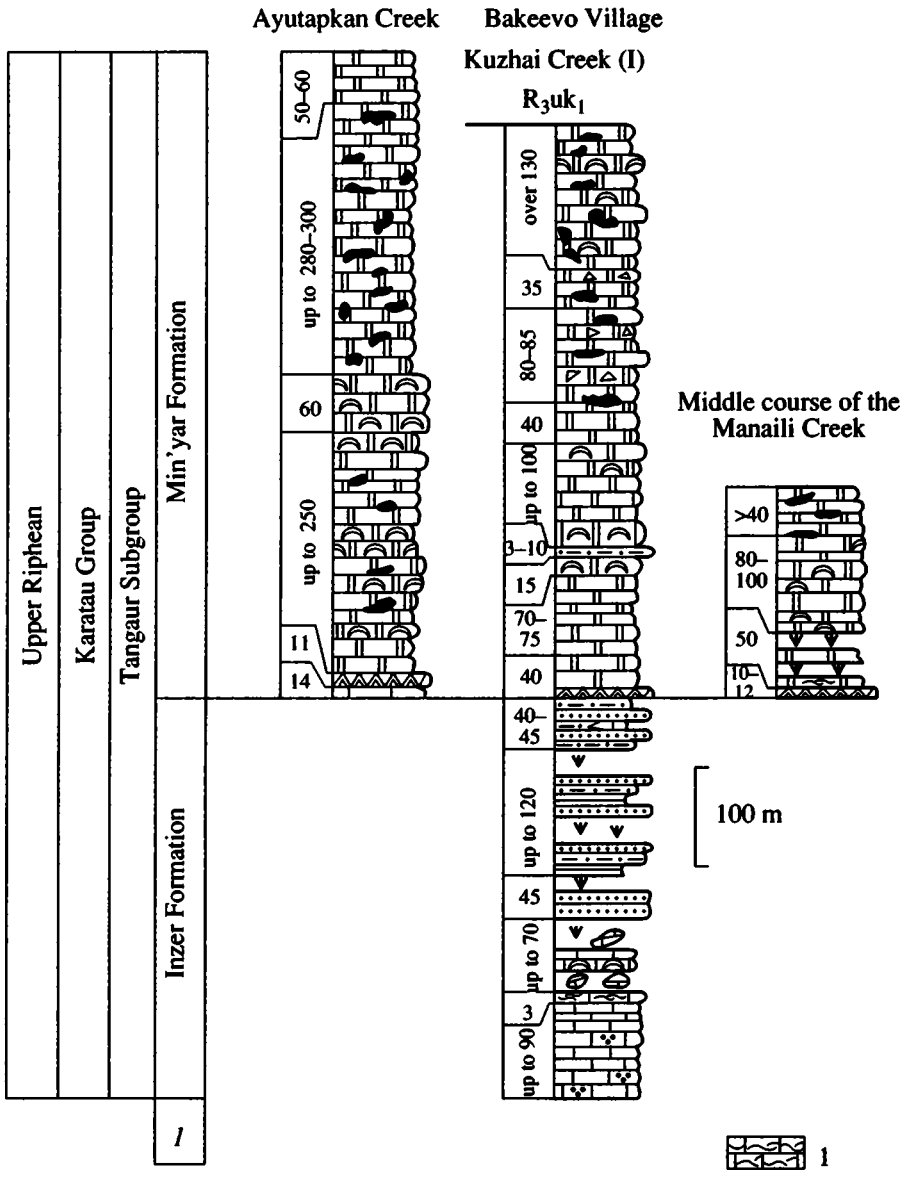

Fig. 6. Geologic columns of Tangaur Subgroup in the western limb of the Bakeevo syncline (section along the Kuzhai Creek in the Bakeevo Village corresponds to locality I in Fig. 2): (1) limestone with microbial lamination; (kt) Katav Formation (other symbols as in Fig. 3; thickness of beds in some columns is given out of scale).

and wavy lamination in the rocks. It is reasonable to assume therefore that the microbial stabilization of sedimentological indications, such as ripple marks and wavy lamination, was of crucial importance for accumulation of the otherwise monotonous limestone sequence. This phenomenon was likely similar to that described for the deposition history of the Belt Supergroup (Schieber, 1999). Abundant molar-tooth structures are also characteristic of carbonate rocks of the lower and middle units. The upper unit 50 m thick unites dark and brown–gray obscurely banded fine- to medium-grained limestones displaying abundant molar-tooth structures. Large *Gymnosolen* bioherms occur in its middle part.

Rocks under consideration are substantially worth exposed within the eastern belt corresponding to the western limb of the Bakeevo syncline. The rock succession of subgroup most completely exposed here is that of the Bakeevo Village locality (Fig. 6, I):

Lower Inzer Subformation

(4) Dark gray pelitomorphic to fine-grained thin- and medium-platy horizontally bedded massive limestones; the thickness is up to 90 m;

(5) Dark gray thin-platy limestones with microbial lamination; the thickness is 3 m;

(6) Unexposed interval up to 70 m wide, hosting debris of dark gray platy and stromatolitic limestones.

Upper Inzer Subformation

(7) Isolated outcrops, talus, and debris of light to brownish gray fine- to medium-grained sandstones with glauconite; the thickness is about 45 m;

(8) Rare outcrops of fine-grained glauconite-bearing sandstones, siltstones, and variegated shales with cross and wavy lamination; the thickness is approximately 120 m;

(9) Irregularly alternating greenish gray fine-grained sandstones, siltstones, and rare limestones enclosing stratiform–nodular and columnar stromatolites; some rock varieties are detrital; the thickness is 40–45 m.

Min'yar Formation

(10) Dark gray medium-grained dolomites with *Conophyton* remains in the lower part; the thickness is 40 m;

(11) Dark gray medium-grained horizontally bedded dolomites; the thickness is 70–75 m;

(12) Dark gray medium-grained dolomites with *Minjaria* remains; the thickness is about 15–17 m;

(13) Isolated outcrops, boulders, and debris of fine-grained sandstones and siltstones with calcareous matrix; the thickness is 3–10(?) m;

(14) Irregular alternation of light gray thick-platy dolomites with bioherms of columnar stromatolites up to 1.0–1.2 m high and of dark gray thin- to medium-platy dolomites; the thickness is 25 m;

(15) Dark gray medium- to thin-platy dolomites with thin horizontal bedding; the thickness is 10 m;

(16) Dark gray medium-grained dolomites; the thickness is 15 m;

(17) Dark gray thin- to medium-platy dolomites with thin horizontal bedding; the thickness is 15–17 m;

(18) Gray thick-platy dolomites with relics of columnar stromatolites; the thickness is 30 m;

(19) Dark gray platy obscurely bedded dolomites; the thickness is about 35–40 m;

(20) Light gray to bluish fine-grained dolomites with intraclastic horizons and chert concretions; the thickness is about 80–85 m;

(21) Gray medium-platy fine-grained dolomites with cherts; the thickness is 30 m;

(22) Dark gray medium- to thin-platy dolomites with intraclastic levels and chert concretions; the thickness is 5–7 m;

(23) Gray to light gray dolomites with cherts and local bioherms of columnar stromatolites; the thickness exceeds 130 m.

The Min'yar Formation is overlain by siliciclastic rocks of the lower Uk Subformation. As one can see, the Min'yar Formation in the above succession includes rocks characteristic of its sections in the western belt. These are dolomites with *Conophyton* remains (the basal part of Bed 10), platy fine- to medium-grained dolomites (the middle and upper parts of Bed 10 and Bed 11), an intricate sequence of dolomites with *Minjaria* remains (beds 19–22), and dolomites with cherts and rare bioherms of columnar stromatolites.

According to Raaben (1985), the Min'yar section exposed along the Ayutapkan Creek south of the Bakeevo Village is of the following structure (Fig. 6):

(1) Light gray dolomitic limestones; the thickness is 14 m;

(2) Dolomitic limestones with stromatolites *Conophyton miloradovichi*; the thickness is 11 m;

(3) Gray to dark gray horizontally laminated dolomites with cherty nodules and stromatolites *Tungussia perforata* and *Parmites nubilosus*; the thickness is up to 250 m;

(4) Gray massive dolomites with several occurrence levels of *Minjaria*; the thickness is 60 m;

(5) Platy dolomites with chert concretions; the thickness is up to 280–300 m;

(6) Light gray platy dolomites; the thickness is 50–60 m;

Another fragment of the Min'yar Formation is exposed along the Manaili Creek upstream of the Smail Creek east of the Kul'tamak farm (Fig. 6).

(1) Thick-platy dolomites with poorly preserved *Conophyton* remains; the thickness is 10–12 m;

(2) Dolomites with microbial lamination; the thickness is 7–8 m;

(3) Unexposed interval up to 15 m wide;

(4) Medium- to coarse-grained dolomites with thin horizontal lamination; the thickness is up to 15–20 m;

(5) Unexposed interval up to 12–15 m wide;

(6) Alternating medium- to thick-platy fine- and medium-grained dolomites and their stromatolitic varieties; the thickness is up to 80–100 m;

(7) Fine-grained medium- to thick-platy dolomites with cherts; the thickness exceeds 40 m.

The Min'yar succession in this section also begins with the *Conophyton* bed overlain by a sequence of platy dolomites (beds 3–5), that is overlain, in turn, by the dolomitic sequence with stromatolites. It is remarkable that the last sequence decreases in thickness from nearly 250 to 45–50 m from the south northward.

FACIES AND THEIR LATERAL VARIATIONS

The Tangaur Subgroup sections, which have been studied in middle courses of the Zilim River across the western limb of the Zilim syncline, include several more or less conditionally distinguishable lithostrati-

graphic units. These are (1) Podinzer Beds of the Inzer Formation (lower Inzer Subformation); (2) lower siliciclastic beds of the upper Inzer Subformation; (3) carbonate beds with stromatolites of the upper Inzer Subformation, formerly the Minka Subformation of the Min'yar Formation (*Stratotip rifeya...* 1983); (4) upper siliciclastic beds of the upper Inzer Subformation; (5) dolomitic beds with *Conophyton* remains or formerly Sukhodol or Adzhigardak members after Raaben (1983) and *Stratotip rifeya...* (1983); (6) dolomitic beds (Kuzhai sequence) separating the mass abundance levels of *Conophyton* and *Minjaria* forms; (7) dolomites with *Minjaria* (Balaevo sequence); and (8) intricate sequence of platy and stromatolitic dolomites with intraclastic horizons and chert concretions (Shubino sequence). A thorough consideration reveals similarity and some distinctions in structure, composition, and rock facies of the Tangaur Subgroup in the eastern and western belts of the Zilim River basin, which are considered below.

The Podinzer Beds are represented in most sections of the western limb of the Zilim syncline mainly by gray to dark gray thin-platy horizontally laminated pelitomorphic to fine-grained limestones (the same rocks are also characteristic of the western limb of the Bakeevo syncline). North of the Karamola Creek, the upper part of this subdivision includes the 60- to 70-m-thick sequence of phytogenic and platy limestones. These rocks are probably missing from section situated southward (except for the section along the Zainysh creek). The Podinzer Beds show a tendency for gradually increase in total thickness from the south to north, namely from approximately 220–230 m in the Zainysh Creek section to 270–280 m in the Kul'tamak Farm and Tolparovo Village sections. Their maximal thickness (about 320–330 m) is established in the Karamola Creek section. The thickness of thin-platy limestones is approximately the same throughout the entire region under consideration and ranges from 230 to 250 m.

The above description of Podinzer Beds shows that they can be divided within the western belt into the lower and upper members. In the southern and central parts of the study region (from the latitude of the Zainysh Creek to the latitude of the Karamola Creek), the lower member is composed of pelitomorphic to fine-grained limestones displaying fine and obscure horizontal lamination and representing products of pure calcareous ooze accumulation in calm settings below the storm wave base. In the middle of the member, a significant role belongs to limestones with wavy lamination and their varieties with ripple marks and rare intraclastite interbeds (the Tolparovo Village section). This implies that limy sediments of calm settings, which are characteristic of southern and central parts of the western belt, were gradually replaced by shallower-water sediments by the moment, when a half of the lower Podinzer Beds was already deposited. These shallower-water sediments accumulated mainly above the fine-weather wave base, but sometimes below this level and above the storm wave base. Consequently, it can be assumed that sedimentation settings of the initial Inzer time (accumulation period of lower Podinzer Beds) were rather uniform throughout the studied area of paleobasin.

Within the western belt, the upper Podinzer Beds occur in separate areas. They are composed of pelitomorphic to fine-grained platy limestones, their microphytolithic varieties (some with fine cross lamination of uniform or multidirectional orientation), and limestones with columnar stromatolites (Fig. 7). In some sections, platy limestones separating stromatolitic buildups reveal distinct erosional surfaces, intraclastic intercalations, and locally developed desiccation cracks. All this implies a substantial shoaling during the sequence accumulation, at least in the northern part of sedimentation basin, and intermittent subaerial exposition of the bottom. It is quite probable that the boundary between the lower and upper Podinzer Beds is event-grounded and marks in the western periphery of the Bashkir meganticlinorium a rather fast transition from mostly deep-water carbonate sedimentation of the initial Podinzer (Tangaur) time to shallow-water subtidal settings of the terminal phase. This also allows an important conclusion that the boundary between the upper and lower Inzer subformations is diachronic in its modern interpretation.

Siliciclastic and carbonate deposits of the upper Inzer Subformation are confidently traceable throughout the entire western limb of the Zilim syncline. Their integral thickness is noticeably variable. It is approximately 350–400 m in the Zainysh Creek section in the south of study region, 160–200 m in the vicinity of the Tolparovo Village, and, probably, 120–130 m near the Akkostyak Cliff and Bala-Elga Creek mouth.[4] The general habit of rocks, which compose the lower and upper siliciclastic sequences of the subformation, point to their deposition in shallow shelf settings above the fine-weather wave base under a low see-level stand (recall thin alternation of different lithologies; small-scale cross, cross wavy, wavy, striated, and other types of bedding frequently outlined by glauconite grains; ripple, current-jet, and other basal marks; signs of primary current lineation, etc.). Sediments of carbonate sequence separating siliciclastic parts were deposited in similar settings. This is evident from some primary indicative features, such as presence of microphytolithic intercalations in platy limestones, shaly laminae and small *Gymnosolen* and *Parmites* bioherms separated by thin layers composed of intraclasts. It should be noted, however, that the carbonate sequence of the upper Inzer Subformation could be only arbitrarily distinguished in some sections of the western limb of the Zilim syncline, whereas it is missing in the western limb of the Bakeevo syncline.

The next well-expressed marker within the Tangaur Subgroup is represented by the *dolomite beds with*

[4] This is likely a response to a small transverse uplift in this area.

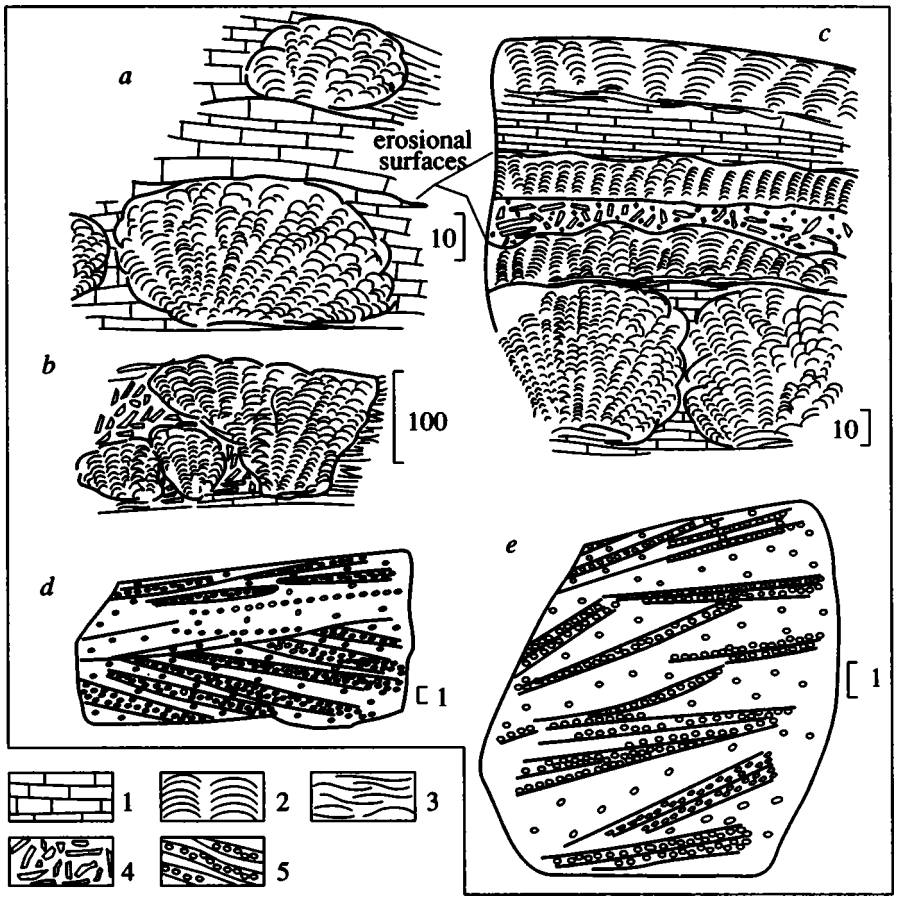

Fig. 7. Small-scale cross and multidirectional lamination in microphytolithic limestones and relation between platy fine- to medium-grained limestones, their stromatolitic varieties, and synsedimentary carbonate breccia with flat clasts, the Podinzer Beds of the Inzer Formation: (1) platy fine-grained limestone; (2) stromatolitic limestone; (3) microbial-laminated limestone; (4) synsedimentary limestone breccia with flat clasts; (5) microphytolithic limestone (scale bar 1 cm). Drawings characterize rocks of the Malyi Shishenyak Creek (*a*), Kuzhai Creek (*b*), Zilim River upstream of the Malyi Tolpar River (*c*), Karamola Creek (*d*), and Mt. Sibentyuk (*e*) localities. Scale bars 1 cm.

Conophyton remains at the base of the Min'yar Formation (Adzhigardak sequence) and traceable in all studied sections except for that exposed along the Zilim River downstream of the Malyi Tolpar River mouth. As was noted earlier (Raaben, 1971, 1981, 1985; Krylov, 1983), accumulation of these beds could be related to stabilization of past sedimentation settings over a significant part of the modern Bashkir meganticlinorium. Absence of detrital and cross-bedded carbonate rocks in association with *Conophyton*-bearing rocks, which are facies-persistent in lateral direction, suggests that deposits in question accumulated in calm settings. Based on stromatolite morphogenesis model (Petrov, 1996) and data of Hoffman (1973) and Grotzinger (1989, 1990), the Adzhigardak sequence largely composed of columnar stromatolites with conical arcs (*Conophyton*) can be considered as deposited in deep settings near the lower boundary of the euphotic zone.

The overlying *beds of variable platy dolomites* (Kuzhai sequence after M.E. Raaben) is 50–60 to 90–100 m thick. Structural peculiarities of their constituting rocks imply that they accumulated mainly in calm hydrodynamic settings below the fine-weather wave base. Dolomites with different-scale multidirectional cross lamination (Figs. 8*a*, 8*b*) occurring at this level in some sections (Karamola Creek and others) suggest that calm environments were unstable, and immature sediments could sometimes be influenced by flow drag.

The higher *dolomite beds with Minjaria* and overlying *dolomite beds with intraclastic intercalations, cherts, and stromatolitic buildups* are composed of sediments accumulated in variable, from active to calm hydrodynamic settings. The thickness of *Minjaria*-bearing beds varies from 80 to about 100–120m. In exposures of the Kuzhai Creek, they enclose a thin siliciclastic intercalation that is considered by many researchers as corresponding to the base of the so-called B'yanka Subformation of the Min'yar Formation (Bekker, 1961; Kozlov, 1982; *Stratotip rifeya...*, 1983). However, this terrigenous layer is observed only in the Bala-Elga Creek section. It was also believed that a characteristic feature of the dolomitic B'yanka Subfor-

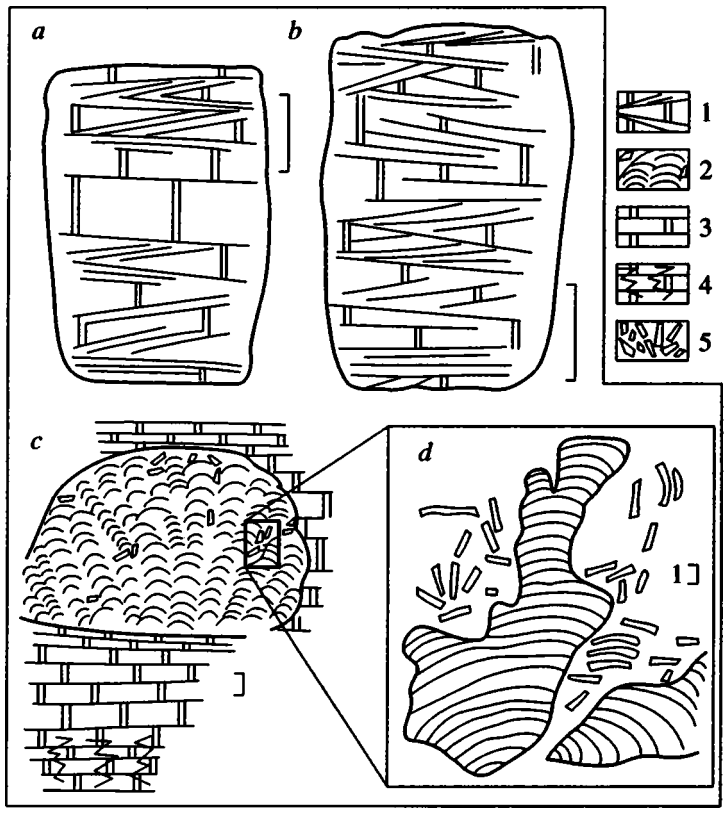

Fig. 8. Thin multidirectional cross and cross wavy lamination in fine-grained dolomites of the Min'yar Formation, the Karamola Creek section, and relationships (*a*, general and *b*, detailed; *c* and *d* see explanation in the text) between stromatolitic fine- to medium-grained dolomites with molar-tooth structures and synsedimentary dolomitic breccia with flat clasts: (1) dolomites with multidirectional cross lamination; (2) stromatolitic dolomite; (3) platy fine- to medium-grained dolomites; (4) dolomite with molar-tooth structures; (5) intraclastic dolomite breccia with flat clasts (scale bar is 10 cm).

mation is the presence of cherty concretions (Bekker, 1961; Kozlov, 1982; Kozlov *et al.*, 1991; *Stratigraficheskie skhemy...*, 1993). Nevertheless, the structure of the Min'yar Formation sections in the Zilim River basin is inconsistent with this standpoint. If we take the base of the dolomitic beds with *Conophyton* for the zero level, then the interval between this and occurrence level of cherts is about 120–140 m in the Ayutapkan, Karamola, Manaili, and some other sections. In the Mt. Sibentyuk section, it corresponds to 360–380 m, and to nearly 400 m in the Zainysh Creek section, being as large as 550 m in the section studied along the right slope of the Zilim River valley downstream of the Malyi Tolpar River. Thus, it is clear that the occurrence of cherts in the Min'yar Formation sections cannot serve as a criterion for referring the enclosing dolomites to the B'yanka Subformation. The basal occurrence level of cherty nodules in the section is undoubtedly diachronic.

The occurrence of intraclastic varieties amid platy dolomites in the upper part of the Min'yar Formation (sections along the Zainysh Creek, near Mt. Sibentyuk, and along the Bala-Elga Creek) points to emergence of local settings with active hydrodynamics, where sediment accumulation was accompanied by penecontemporaneous breaking of carbonate laminae cemented during the early diagenesis. A high hydrodynamic activity is also evident from low-amplitude incisions observed in stromatolite buildups (Figs. 8*c*, 8*d*; Figs. 9*a*, 9*b*, 9*c*) and/or enclosing rocks, and from permanent association of stromatolites and intraclastic rocks, in which some intraclasts represent stromatolite fragments.

In terms of a general development model of the Late Riphean sedimentation basin (Maslov, 1997b), the following evolutionary trend of the Tangaur basin can be outlined. Within the entire Bashkir meganticlinorium, the initial Karatavian was a time of a large regression and deposition of thick siliciclastic wedge of alluvial and alluvial–deltaic sediments of the Bir'yan Subformation of the Zilmerdak Formation. By the mid-Zilmerdak time, the regressive trend changed into transgressive one that resulted in accumulation of terrigenous tidal, subtidal, and shallow-water marine facies (Lemeza and Bederysh subformations). In the Katav time, the last trend continued, and fine-grained red-colored carbonate ooze with a substantial admixture of pelitic siliciclastic material accumulated under condi-

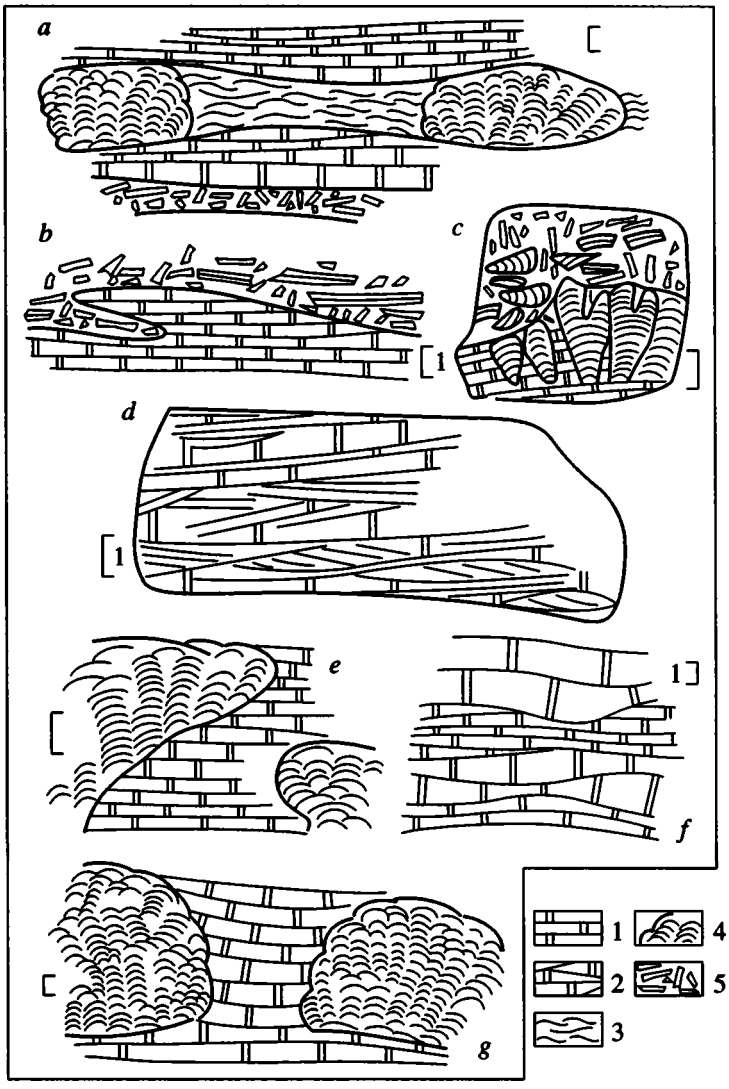

Fig. 9. Structural peculiarities and relationships between (1) platy dolomite, (2) cross-bedded dolarenites, (3) dolomite with microbial lamination, (4) stromatolitic dolomite, and (5) intraclastic dolomite breccia of the Min'yar Formation, sections: (*a*) the Zilim River down stream the Zainysh Creek mouth, an upper part of the formation; (*b*) ditto, uppermost levels of the formation; (*c*) the Manaili Creek upstream of the Smail Creek; (*d*) left bank of the Zilim River southwest of Mt. Sibentyuk; (*e*) the Zilim River upstream the Malyi Tolpar River mouth; (*f*) the Zainysh Creek, hummocky lamination; (*g*) left bank of the Zilim River near Mt. Sibentyuk (scale bar is 10 cm unless other is indicated).

tions of a low sea-level stand almost over the entire Bashkir meganticlinorium. The permanent occurrence of pelitic clayey component in the carbonate matrix of rocks from western sections of the Katav Formation suggests the basin expansion toward adjacent, relatively peneplanated drainage areas. By the beginning of the Inzer time (accumulation time of the Podinzer Beds), the influx of fine-grained siliciclastic material from the west ceased. This time probably corresponds to the beginning of substantial basin deepening. Variegated clayey limestones in the uppermost part of some Katav Formation sections (e.g., in the vicinity of Tolparovo and Bakeevo villages) enclose thin interbeds of dark gray pelitomorphic limestones of the Podinzer type, which imply a gradual transition between two lithostratigraphic units and gradual basin deepening. The transitional member itself can be considered as representing sediments of the transgressive facies system.

According to previous lithological–facies and paleogeographic interpretations (Maslov, 1986b, 1987, 1988), shallow-water siliciclastic and carbonate sediments, including phytogenic ones, were prevalent in the sedimentation basin of the Inzer time, while terrigenous subtidal sediments were of subordinate significance. The latter are characteristic only of southeastern areas of the meganticlinorium (basin of Belaya River right tributaries), whereas the former compose all known

sections of the Inzer Formation in the central and western areas. The southeastern zone of siliciclastic sediments accumulation under the prevalent influence of surge currents, central one with prevalent shallow-water marine terrigenous sedimentation, and western zone, where preponderant calcareous sediments accumulated can be distinguished in the study region for the beginning of the Inzer time.[5] At the end of the Inzer time, western and northwestern areas of the meganticlinorium accumulated shallow-water marine siliciclastic and carbonate sediments, whereas shallow-water sandy–silty–clayey facies were deposited in central areas. Accumulation of fine-grained terrigenous sediments was prevalent in the northeastern part of the meganticlinorium, and its southeastern part represented an area of tidal surge-current influenced and normal marine shallow-water sedimentation settings. The remarkable facies diversity at the initial stage of Inzer basin development gave way to their virtual uniformity by the end of Inzer time.

Let us consider now how the discussed materials fit the general scheme of region development. At the beginning of the Inzer (more exactly, Podinzer) time corresponding to the accumulation period of the lower sequence of the Podinzer Beds, pure calcareous ooze accumulated under calm conditions below the storm wave base in the southern and central parts of the study region. In the middle of this period, they were replaced in the northern areas by relatively deep sediments, accumulation of which was influenced by both the stormy and fine-weather waves. The nearly uniform thickness of the lower Podinzer beds throughout the entire study region and progressing unification of sedimentation settings imply a relative synchronism of their upper boundary in the Zilim River basin. The transition from thin-platy pelitomorphic to fine-grained limestones to stromatolitic, microphytolithic, detrital, and pelitomorphic rock varieties in the northern part of the region, or to lower siliciclastic strata of the upper Inzer Subformation, which accumulated in shallow-water settings above the fine-weather wave base in southern and central areas, allows me to consider conditionally the boundary between the lower and upper Podinzer Beds as corresponding to event that separated systems of the high and low sea-level stands and, probably, to the flooding surface.

The next stage of the Tangaur paleobasin development under conditions of the low sea-level stand resulted in formation of intricate complex of siliciclastic and carbonate rocks. In northern areas, a lower portion of that complex is composed of phytogenic, detrital, and platy pelitomorphic limestones (the upper Podinzer Beds). In the central and southern areas, these rocks are replaced by a member of alternating glauconite-bearing siltstones, fine-grained sandstones, and shales constituting basal beds of the lower siliciclastic sequence of the upper Inzer Subformation. Overlying strata (the upper part of mentioned sequence) are composed of sandy–silty–clayey and/or silty–clayey sediments deposited above the fine-weather wave base. Higher in the section, there are terrigenous and carbonate sediments (middle carbonate beds), which accumulated in shallow basin areas and probably replace each other in lateral direction. Uppermost siliciclastic beds of the upper Inzer Subformation also represent the shallow-water marine sediments judging from their structural–textural features.

In the Min'yar period, carbonate sedimentation spanned over the entire Bashkir meganticlinorium. At the Adzhigardak time of that period, thin dolomite beds with *Conophyton* remains were deposited almost everywhere except for the southeastern part of the region (basin of Belaya River right tributaries), where the concurrent level is occupied by chemogenic dolomites. Carbonate sediments of the Kuzhai time accumulated in calm hydrodynamic settings below the fine-weather wave base. Thick sequence of subtidal dolomites with columnar stromatolites (northern part of the meganticlinorium) and intricate succession of relatively deep-water platy and stromatolitic dolomites (central and southern areas) accumulated in the Balaevo time (Figs. 9*d*–9*g*). Finally, thin-bedded dolomites with subordinate amount of varieties with columnar stromatolites formed in shallow and moderately deep settings over the entire meganticlinorium in the Shubino time.

Let us analyze the structure of the Tangaur Subgroup once more. The boundary between the Inzer and Min'yar formations is distinguishable only in the Zilim River section upstream of the Bala-Elga Creek, although there are many other sections of the subgroup in the region. The contact between siliciclastic sediments of the Inzer Formation and carbonate deposits of the Min'yar Formation characterizes here, in my opinion, a sharp rather than gradual transition. Dolomites with *Conophyton* remains accumulated most likely under the high sea-level stand (see above for argumentation), and the Inzer–Min'yar boundary appears to be event-grounded. I do not exclude a hiatus between these subdivisions, which has been previously assumed by Raaben (1975, 1981) based on some other considerations and recently confirmed by data on carbon isotope variations in sediments (Podkovyrov *et al.*, 1998).

Higher levels of the Min'yar Formation (dolomites with *Minjaria* and Shubino sequence) are obviously composed of sediments formed under the low sea-level stand on of the carbonate platform. Platy, horizontally bedded dolomites with rare stromatolitic buildups, which overlie beds with *Conophyton* remains, are transitional between these beds and deeper sediments of the Adzhigardak sequence.

Thus, sections of the Tangaur Subgroup exposed in the western limb of the Zilim syncline are used here to outline in terms of the event stratigraphy the develop-

[5] The Inzer time is considered here as a period, during which sediments of the Podinzer Beds accumulated in the western part of the meganticlinorium, while a part of thick (up to 800–1000 m) siliciclastic succession was deposited in its central part.

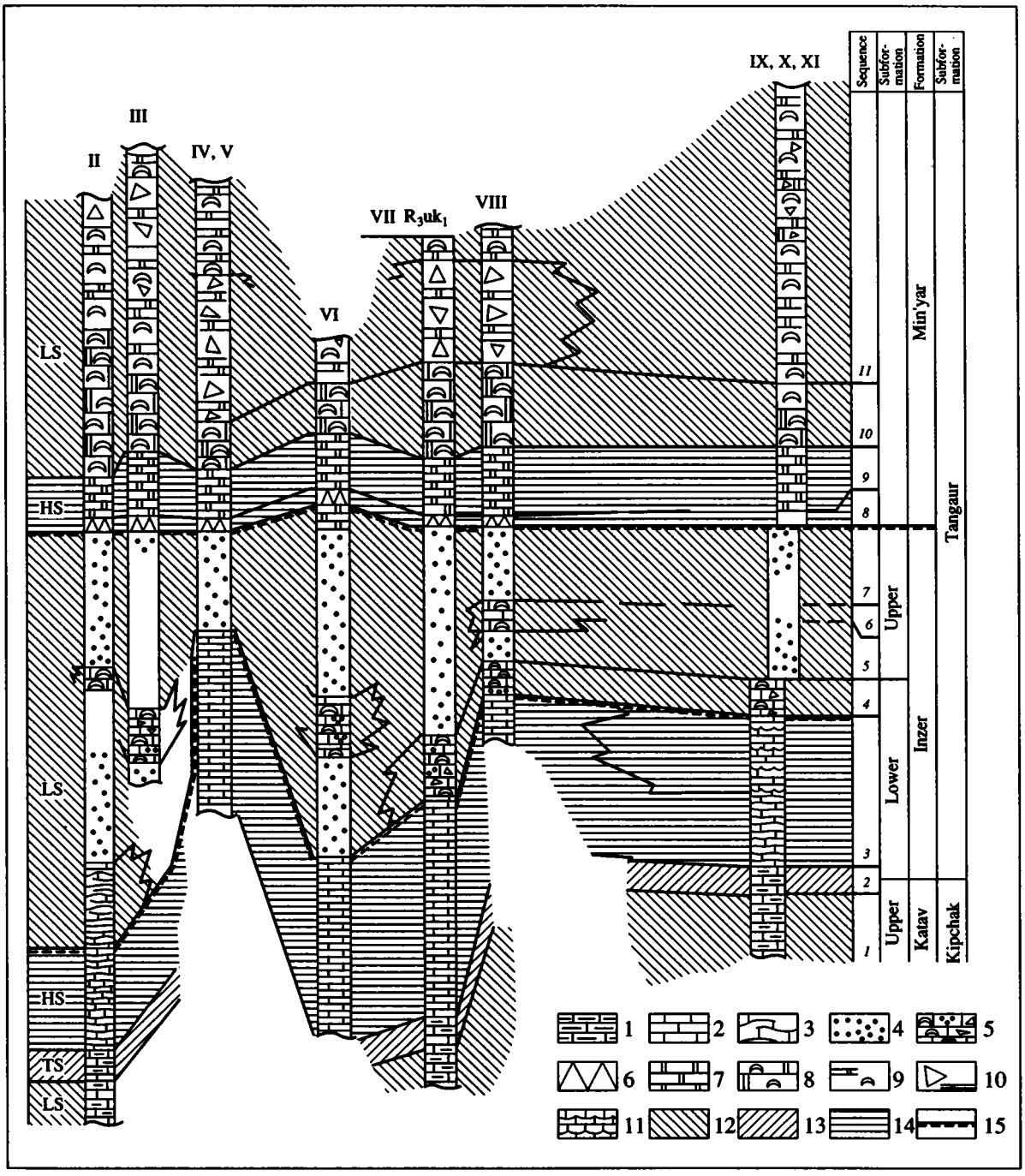

Fig. 10. Relationships between facies systems and general development of the mid-Late Riphean sedimentation basin: (1) red-colored and variegated clay limestones; (2) thin-platy limestone with thin horizontal lamination; (3) limestones with microbial lamination; (4) siliciclastic rocks; (5) limestones with columnar stromatolites, microphytoliths, and interbeds of detrital varieties and intraclastic breccias; (6) dolomites with *Conophyton* remains; (7) thin- to medium-platy fine- to medium-grained dolomites with rare stromatolites; (8) thick-platy dolomite with *Minjaria*; (9) platy dolomites with cherty concretions and abundant interbeds of intraclastic breccia; (10) detrital platy dolomites with columnar stromatolite buildups, their detrital varieties, and chert concretions; (11) platy pelitomorphic fine-grained limestones with horizontal to wavy lamination and ripple marks. Facies systems: (12) lower sea-level stand (LS), (13) transgressive (TS), (14) high sea-level stand (HS); (15) event-grounded boundary. Stratigraphic units of the Tangaur Subgroup: (*1*) upper sequence of the upper Katav Subformation, (*2*) transitional member between the Katav Formation and Podinzer Beds, (*3*) lower Podinzer Beds, (*4*) upper Podinzer Beds, (*5*) lower siliciclastic beds of the upper Inzer Subformation, (*6*) middle carbonate beds of the upper Inzer Subformation, (*7*) upper siliciclastic beds of the upper Inzer Subformation, (*8*) dolomite beds with *Conophyton* remains, (*9*) platy dolomites overlying dolomite beds with *Conophyton* remains and occurring below the level with abundant *Minjaria* remains, (*10*) dolomite beds with *Minjaria*, (*11*) beds of platy and stromatolitic dolomites with chert concretions and interbeds of intraclastic breccia (see localities of study II–XI in Figs. 2 and 3).

ment model of the Riphean sedimentation basin that covered the present-day area of the Bashkir meganticlinorium (Fig. 10). At present, publications dedicated to the Riphean evolution of Eurasia are not numerous, and only few of them are of particular interest, e.g., those considering the Upper Riphean sections of the Turukhansk uplift (Petrov and Semikhatov, 1997, 1998; Petrov *et al.*, 1995).

CONCLUSION

Comparison of the Tangaur Subgroup sections exposed in the middle courses of the Zilim River basin between each other and with synchronous sections in adjacent areas of the Bashkir meganticlinorium shows their rather persistent structure, on the one hand, and certain lateral and vertical variations, on the other. The beds with *Conophyton* remains at the base of the Min'yar Formation, as well as the overlying dolomitic sequence up to the level of *Minjaria* mass abundance and the lower Podinzer beds composed almost completely of pelitomorphic to fine-grained limestones are most stable elements well expressed in all sections of the subgroup. The sequence of phytogenic, platy and detrital limestones crowning the Podinzer beds and stretching within the western belt over a distance of 12–15 km southward of the Tolparovo Village points to a substantial shoaling of the sedimentation basin by the end of early Inzer (Podinzer) time. Desiccation cracks and erosion marks in "stromatolite heads" at the surface of stromatolitic limestones crowning the upper Podinzer Beds upstream of the Malyi Tolpar River mouth even imply a subaerial exposition of the basin bottom.

The inferable sedimentation settings of the lower and upper Podinzer Beds suggest that the boundary between these subdivisions is event-grounded. It marks a transition from the facies system of the high sea-level stand to siliciclastic and carbonate deposits accumulated largely above the fine-weather wave base. Thus, the upper boundary of the Podinzer Beds well mapped within the western limb of the Bashkir meganticlinorium is diachronic.

In the western belt of its distribution in middle courses of the Zilim River, the Inzer Formation includes two carbonate and two siliciclastic members. The same structure is characteristic of the formation in the entire external facies zone of the Bashkir meganticlinorium, from the Alatau anticlinorium extremity in the south to the Min'yar outskirts in the north (Maslov and Krupenin, 1991; Podkovyrov *et al.*, 1998). In other words, it was persistent, though with some variations, along the entire regional paleoslope. To the contrary, the structure of the Inzer Formation substantially changes from the west eastward, i.e., across the paleoslope. For instance, it comprises the lower carbonate (Podinzer Beds) and upper siliciclastic sequences in the western limb of the Bakeevo syncline, whereas only one, but very thick (up to 800–1000 m) terrigenous succession can be observed in the Inzer synclinorium between the Katav Formation and dolomite beds with *Conophyton* remains at the base of the Min'yar Formation. The overlying dolomitic succession, like the underlying Katav Formation, shows in the last case structural features, which are identical to those characterizing these subdivisions in the middle courses of the Zilim River. It is clear that such relationships between siliciclastic and carbonate successions cannot represent a result of spatial convergence of tectonic blocks with different types of sections, as it was thought previously. It is more reasonable to assume that clastic material fluxed into the Inzer basin mainly from the east or southeast that resulted in present-day relationships between major facies zones observable in the Bashkir meganticlinorium, where the near-shore zone with siliciclastic sediments is located in the east and southeast, the central zone hosts prevalent shallow-water marine terrigenous sediments, and alternation of carbonate and terrigenous sediments is characteristic of the western zone (Maslov, 1986b, 1987, 1988).

In the middle courses of the Zilim River, the upper part of the Tangaur Subgroup is rather uniform in structure. The middle and upper parts of the Min'yar Formation probably accumulated under conditions of the low sea-level stand in a vast carbonate platform, where sedimentation settings were of active hydrodynamics in general, though variable. In contrast, sediments of the lower formation part were deposited under conditions of a higher sea-level stand.

Judging from materials discussed above, the formation time of the Tangaur Subgroup in western periphery of the Bashkir meganticlinorium can be considered as an epoch of sedimentation in a large, rather stable epicontinental sea basin, evolution of which was intricate. The analyzed composition and facies variability of the Tangaur Subgroup imply that several systems of the high and low sea-level stands, which are separated by isochronous boundaries, can be distinguished in the studied rock succession.

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Trends in Development of Late Devonian Reefs

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Abstract—The Late Devonian was a period of degraded reef formation that was very intense in the Middle Paleozoic. Principal reef-building organisms, such as stromatoporoids, rugoses, and tabulates of the Frasnian Stage, were replaced by Famennian cyanobacteria and algae at that time. This resulted in development of Famennian frameless buildups instead of Frasnian framework reefs since the late Frasnian through the early Famennian. The difference in tectonic settings of reef development in continental and oceanic stratisphere segments is established. In oceanic segments, the frameless reefs were likely formed earlier than in continental settings.

Key words: Late Devonian, reefs, evolutionary reef formation.

INTRODUCTION

In the Earth's history, the Late Devonian was a terminal stage of the Middle Paleozoic reef development (Talent, 1988; Cooper, 1989; Ivanovskii *et al.*, 1994; Kuznetsov, 1996a, 2000). It was a time of global mass extinction and renewal of faunas across the Frasnian–Famennian boundary (Donovan, 1989). The event is thought to be caused, like some other global extinctions, by an extraterrestrial factor, e.g., by impact of asteroid or large meteorite (Clayes *et al.*, 1992). A sudden change in biota should influence the development of reef-forming process in the Late Devonian that is of particular scientific interest, because it was a period characterizing degradation of the process in contrast to other periods of maximal reef development, which are usually under attention. The interest is natural therefore, but generalizing works on Devonian reefs are rare despite a great number of publications devoted to their description in separate regions.

When analyzing reef development with time, it is important to have a possibility of subdividing sections in detail and of correlating them confidently in order to precisely define the commencement, prosperity, and cessation time of reef formation periods. Unfortunately, boundaries of some stratigraphic subdivisions (e.g., those of the Givetian and Frasnian stages) do not coincide in the domestic and international scales. An alternative is to use the conodont zonations, in which units lesser than a stage are distinguished, and which enable the intercontinental correlation and tracing of subdivisions over the globe. Figures presented here to illustrate trends in development of Late Devonian reefs include two conodont scales: the initial one (Ziegler, 1971) that was used when elaborating of the Unified Stratigraphic Scale for Devonian deposits in the Russian platform and adjacent areas (*Reshenie...*, 1990), and the other scale revised recently (Barskov *et al.*, 1988; Ziegler and Sanberg, 1984, 1990; Rodionova *et al.*, 1995; Alekseev *et al.*, 1996; Ovnatanova and Kononova, 1999).

In general, I analyzed the following three aspects of the Late Devonian reef formation: paleotectonic settings and paleogeographic distribution of reefs at that time, trends in reef development across the Frasnian–Famennian boundary, and distinctions between reef formation in epicontinental and oceanic basins.

GEOGRAPHIC DISTRIBUTION OF UPPER DEVONIAN REEFS

Any generalization cannot guarantee that all the objects on the globe have been taken into consideration. Anyway, the Upper Devonian reefs appear to be less widespread that those formed during the preceding Middle Paleozoic period of intense reef formation. The most complete database on reefs of the world (Fluegel and Fluegel-Kahler, 1992) clearly shows that they are known in a restricted number of regions and structures. So it is clear that this review includes not all the reefs and their distribution areas. In addition, some considered objects may be biostromes or bioherms, but not the reefs in a strict sense, although I tried to exclude the former buildups from consideration, when it was possible. The analyzed reefs represent both the framework and frameless buildups of the ooze-mound type (Kuznetsov, 1996c, 1996d). Despite all, I believe that regions taken into consideration objectively reflect the situation and elucidate the general paleogeography and paleotectonics of the Late Devonian reef formation.

In the East European platform, abundant Upper Devonian reefs have been discovered along its eastern margin, where a belt of pericratonic subsidence extends from islands of the Arctic Ocean, through the Pechora

syneclise, Volga–Urals region, and Cis-Urals, to the Caspian syneclise (see below for details).

Along the eastern slope of the Urals, the Late Devonian reef formation was considerably reduced as compared to that of the Silurian–Lower Devonian time. Comparatively small reefs of the uppermost Frasnian stage occur among siliceous shales at sides of the flysch trough. These reefs are buried under graywackes of the Zilair Formation. The reef-building organisms are mostly represented by abundant stromatoporoids associated with less abundant receptaculites and cyanobacterial to algal stromatolites *Girvanella, Izhella, Shuguria, Epiphyton, Garwoodia, Tubomorphophyton, Poncetella, Solenopora, Katavella*, and others.

In northeastern Russia, a series of reefal systems is distinguished in the Omulevskii, Tas-Khayakhtakh, and other zones surrounding the Alazeya massif that was detached from the Siberian platform in the earliest Ordovician time. Reefs, which are poorly studied, and concurrent volcanogenic-sedimentary deposits originated along periphery of the detached block. Some of them are attributed to the undivided Devonian, and the more precise Givetian–lower Frasnian age is defined for others, because the upper Frasnian non-reefal deposits "overlie reefal limestones with the angular unconformity" (Vishnevskii and Vaganov, 1986, p. 97). The reef-builders were cyanobacteria, algae, stromatoporoids, rugoses, tabulates, and receptaculites. The Givetian–lower Famennian reefs of the Alazeya massif proper bear recrystallized remains of stromatoporoids and corals.

Reefs of the Givetian–Frasnian age are known as well in the Salair Range, Altai Mountains, and under sedimentary cover of the epi-Hercynian West Siberian platform. Their chains surround the Salair microcontinent and Nyurol'ka block now buried under the sedimentary cover. In Kazakhstan and Central Asia, reefs are associated with tectonic structures of two types: the rigid massifs (microcontinents) and volcanic arcs. In central Kazakhstan, reefal deposits around the microcontinent laterally grade into the flyschoid clayey–cherty–carbonate facies and into marine limestones, tuffs, and siliciliths. Predominantly upper Famennian and, probably, Tournaisian algal reefs of a similar type are known in the Bol'shoi Karatau zone of central Tien Shan. In the Turkestan–Alai segment, reef barriers of a wide stratigraphic range (Upper Silurian–Lower Carboniferous, the upper Devonian inclusive) surround the Alai microcontinent and South Fergana block, a former shoal inside a deep sea basin.

Reefs connected with volcanic belts are established in the Dzhungar–Balkhash fold system, where they are components of the Upper Devonian Tournaisian sequence composed of cherty shales, tuffites, and andesite horizons. Their precise age is unknown here. Similar reefs built by cyanobacteria, stromatoporoids, and corals are also characteristic of the South Gissar and East Alai zones.

The Middle–Upper Devonian reefs are comprehensively studied in central Europe, namely in the Ardennes, Rhine Mountains, and Harz (Franke, 1973; Krebs, 1974; Bless *et al.*, 1980; Fuchs, 1990; Weller, 1991). Formation of framework reefs commenced here in the Eifelian or Givetian time and lasted up to the latest Frasnian, the Upper *Palmatolepis gigas* Zone inclusive, but it ceased completely at the time of *P. triangularis* Zone. Reefs rimed as barriers the inner uplifts of past sea basins, for instance, the Brabant massif (Belgium–Holland platform), and developed in the Rhine and Saxony–Thuringia basins. Small reefal buildups were characteristic of shallow shelf zones of inner basinal uplifts. Further to the east and southeast, the Upper Devonian buildups are known in Moravia and Silesia. The Famennian reefal mounds of the Ardennes–Rhine zone have been described as "Marble Rouge a Crinoides de Baelen" characteristic of the Souverain-Pre Formation and spanning stratigraphic interval of the Upper *Palmatolepis magnifera*–Lower *Scaphygnathus velifer* zones of the conodont scale (Dressen *et al.*, 1985). In Asturias and Sierra de Cantabria of northwestern Spain, Givetian to lowermost Famennian reefs span stratigraphic interval of the Middle *Polygnathus vargus*–Middle *Palmatolepis triangularis* zones. They have been likely formed within the past Iberian microcontinent (Loevezijn, 1987). Barrier reefs and isolated small buildups, which were built by Frasnian stromatoporoids, rugoses (*Phillipsastreides*), tabulates (*Alveolites, Thamnopora*), and cyanobacteria (*Renalcis, Rothpletzella, Girvanella*, and others), are present in Afghanistan, where they are confined to a linear belt located westward of the Kabul–Ghazni line (Mistian, 1980).

Western Canada is one of classical regions, where Middle to Upper Devonian reefs are widespread. Their chains extend here from Arctic Islands and Mackenzie River basin, through the West Canadian basin and its orogenic frame, to the southern boundary of the country and adjacent areas of United States. The Upper Devonian reefs of western Canada are considered in detail below.

Available reviews (Birenheide, 1978; Hladil, 1986; Fluegel and Fluegel-Kahler, 1992) also report on occurrence of Devonian reefs in other localities. These are plateau Causse Noir of France, Carnic Alps, Turkey, Iran, northwestern Africa (Morocco), southern China, Vietnam, and some other regions.

PALEOTECTONICS AND PALEOGEOGRAPHY OF UPPER DEVONIAN REEFS

The disposition schemes of Paleozoic continents, which have been reconstructed by Scotese and McKerrow (1990) and later on by Golonka *et al.* (1994), are used in this work to analyze paleogeographic distribution of Upper Devonian reefs (Fig. 1).

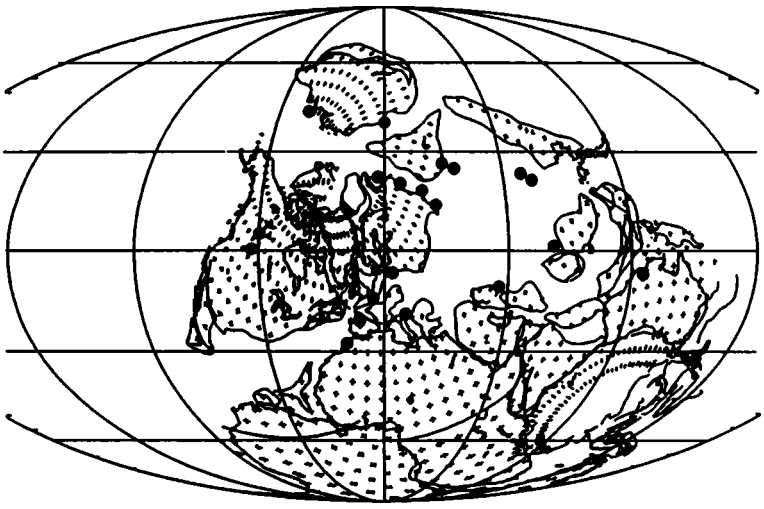

Fig. 1. Paleogeographic localities (black circles) of Upper Devonian reefs (Paleozoic world map after Scotese and McKerrow, 1990).

As one can see from Fig. 1, Upper Devonian reefs of the Alazeya zone and western Canada developed in eastern shelf areas of the Paleopacific ocean. Concurrent reefs, which are situated now in the western Urals and along eastern margin of East European platform, originated in the southern shelf and along slope breaks of the Uralian paleoocean that was closing at that time. Reefs of the Altai, Salair Range, and West Siberia characterize buildups of the Paleoasiatic ocean that was also at the stage of closure. Reefs known in western and central Europe, Spain, northern Africa, northern Italy, Afghanistan, and northern Australia developed in the newly formed sublatitudinal Paleotethys. They were situated in the shelf zone of the latter and surrounded as well the inner oceanic rises (microcontinents) and volcanic structures in narrow troughs.

Owing to a small scale of the paleotectonic scheme, it is more difficult to specify disposition of reefs distinguished in Kazakhstan and Central Asia. Helpful in this case are paleotectonic reconstructions by Zonenshain *et al.* (1990), which clarify distribution patterns of some microcontinents and volcanic belts. In general, reef of both regions developed in the Turkestan paleoocean that represented a northern branch of the Paleotethys. Some of them surrounded margins of the Kazakhstan and Tarim–Karakorum microcontinents or the smaller Alai and South Fergana continental blocks, whereas others originated within the South Tien Shan, Dzhungar–Balkhash, East Alai, and South Gissar volcanic arcs. Their position in the scheme is shown rather tentatively.

In their absolute majority, the Upper Devonian reefs were confined to the paleolatitudinal zone between 30°N and 30°S, i.e., they developed, like recent reefs, within the warm climatic belt. However, reefs of eastern and western Siberia, which advanced as far to the north as 40–45°N, represent an exception. Their localization in high latitudes used to be explained by the polar wandering and by the South Pole position in the South Atlantic (Chuvashov, 1966).

In terms of new geological paradigm of moving continental plates, the above phenomenon may have another explanation. First, the abnormal localization of Siberian reefs cannot be a consequence of erroneously reconstructed disposition of lithospheric plates, because the Siberian platform is uniformly placed in all paleotectonic scheme available so far (Birenheide, 1978; Zonenshain *et al.*, 1990; Scotese and McKerrow, 1990; Khain and Seslavinskii, 1991; Golonka *et al.*, 1994). Trying to explain the abnormal advancing of upper Devonian reefs to high latitudes, I have suggested once that expansion of thermophilic reef-building organisms far to the north, in the temperate latitudes, could be stimulated by the warm climate of the Middle Devonian–Frasnian time (Kuznetsov, 1996b). The global distribution patterns of reefs allow me to add one more factor clarifying the above explanation.

The fact is that western margins of continents are lacking reef at present, because they are under influence of the upwelling systems, cold waters of which depress development of reefs in these zones. Devonian reefs were concentrated in western margins of Euramerica (western Canada) and East Siberia, and I do not exclude that a great and warm oceanic current, like the present-day Gulf Stream, was active here in the past. First, this current was favorable for development of reefs, and second, it warmed up the southwestern coastal zone of East Siberian continent and could penetrate in the Paleoasiatic ocean to stimulate the reef formation there. Assuming that the current did not penetrate far to the south, we can explain why reefs are unknown within similar latitudes of the southern hemisphere.

DEVELOPMENT OF LATE DEVONIAN REEFS

As is stated before, we can understand details of reefs development with time, if only the detailed stratigraphy of necessary sections is known. Such sections, which allow us to establish the commencement, peak phase, and cessation of reef-forming process, are rare, and I consider below only several regions studied better than others.

Timan–Pechora Province

In the North, Near-Polar, and Polar Urals, reefs were discovered already in the 1930s. Geological prospecting for oil and gas that was initiated in the 1960s recovered buried reefal deposits in the Pechora syneclise and adjacent part of the Uralian foredeep, so that now they are studied in detail (Menner *et al.*, 1989; Antoshkina, 1994; Belyaeva *et al.*, 1998). Despite an element of uncertainty in reefal terminology and stratigraphic details, the available materials characterize rather well the development history of reefs in the region (Fig. 2).

The reef formation commenced here in the Semiluki (Domanik) time (interval of the upper *Polygnathus asymmetricus* and *Ancyrognathus triangularis* conodont zones). This was a period of two important events, when a vast transgression was concurrent to activation of tectonic movements, which differentiated the sea-bottom relief. Shallow western and northwestern areas of the past regional basin accumulated shallow-water carbonate deposits intercalated with less abundant terrigenous–carbonate sediments, whereas uncompensated depressions represented depositional settings of bituminous-siliceous and clayey-carbonate sediments of the Domanik type. An asymmetric extended system of reefs was concurrently under development along a zone separating different rock facies. Isolated shoals within the relatively deep part of the basin accumulated shallow-water limestones; some of them were rimmed by reefs along their slope breaks, and others had reef caps. Situation like this lasted, though with minor pauses, throughout the Late Devonian. The short-term regressive phases depressed the reef formation, and terrigenous, predominantly clayey material accumulated in shallow shelves and their slopes forming tracts or terraces, which sloped toward the basin, and external edges of which served as basement for the next generation of reefs originated at the time of subsequent transgression. Concurrent solitary reefs appeared as well in the inner basin areas and aggraded upward older isolated reefs or their chains around shoals. As is established at present, there were two reef-formation phases in the Domanik time, five or six during the late Frasnian—two of the Sirachoi (terminal Rechitsa–Voronezh) and three or four of the Ukhta (Evlanovka–Livny) period, and three during the Famennian (Menner *et al.*, 1991b). These phases can be integrated into the larger Semiluki, Sirachoi, Ukhta, and middle–late Famennian cycles (Antoshkina and Eliseev, 1988). The diverse views on the Famennian phases appeared when upper reefs of the Khar'yaga area, which have been formerly attributed to Frasnian Stage, were interpreted anew as the lower Famennian buildups. This interpretation is based on recognition of the early Famennian phase, although the majority of reefs developed in the middle–late Famennian.

Migration of reefal systems in space was of a different style and magnitude. It depended on the contrast and intensity of tectonic movements and on the influx rate of terrigenous material that controlled the width of terrigenous slope terraces and thus the displacement magnitude of reefal systems. Some reefs successively developed at the same place as a single massif (Frasnian reefs of this kind can be as thick as 400–450 m, and their separate phases are up to 150–200 m thick; similar Famennian reefs are 200–220 m thick). In other cases, reefs migrated seaward with time so that now each subsequent buildup of a series overlies slope of the preceding one. Finally, reef systems of different age can be essentially separated from each other. According to these distribution patterns, the Domanik, Sirachoi–lower Ukhta, Domanik–lower Ukhta, upper Ukhta, upper Frasnian, lower Famennian, lower–upper Famennian, Domanik–middle Frasnian–Zadonskii, and upper Frasnian–lower Famennian reef systems are distinguished (Fig. 2).

Frasnian reefs are clearly distinct from those of the Famennian Stage, and intensity of their formation was higher. They are more widespread than the Famennian reefs. In many regions, Frasnian reefal massifs are overlain by Famennian laminated limestones and dolomites of a shallow-water non-reefal origin. In addition, Frasnian reefs are noticeably thicker, and many Famennian buildups are classed with sedimentary sequences of flat shoals, but not of the moundlike structures.

Another principal distinction is difference in composition of reef-building organisms. Frasnian reefs have been built by stromatoporoids (*Stromatopora, Amphipora*), receptaculites, calcareous algae, and cyanobacteria. Principal taxa of algae were red *Solenopora* and *Parachaetetes*, green tubular *Issinella* and *Paleoberesella*, charophyte *Umbrella*, and *Codium*. Cyanobacteria represented genera *Girvanella, Renalcis, Izhella, Epiphyton, Shuguria, Chabakovia, Rothpletzella, Sphaeocodium, Bevocastria*, and *Coactilum*. All these basic builders associated with rugoses, tabulates, crinoids, foraminifers, brachiopods, and some other invertebrates. Famennian reefs are barren of frame-forming stromatoporoids, receptaculites, and corals. Nearly all of them have been formed by cyanobacteria and calcareous algae. Accordingly, the Famennian reefs are composed mostly of patterned grumous and oncolitic limestones instead of biohermal framestones typical of the Frasnian buildups. In all cases, primary limestones are dolomitized, sometimes intensely. It should be noted as well that stratigraphic distribution of stromatoporoids is debatable to some extent. For

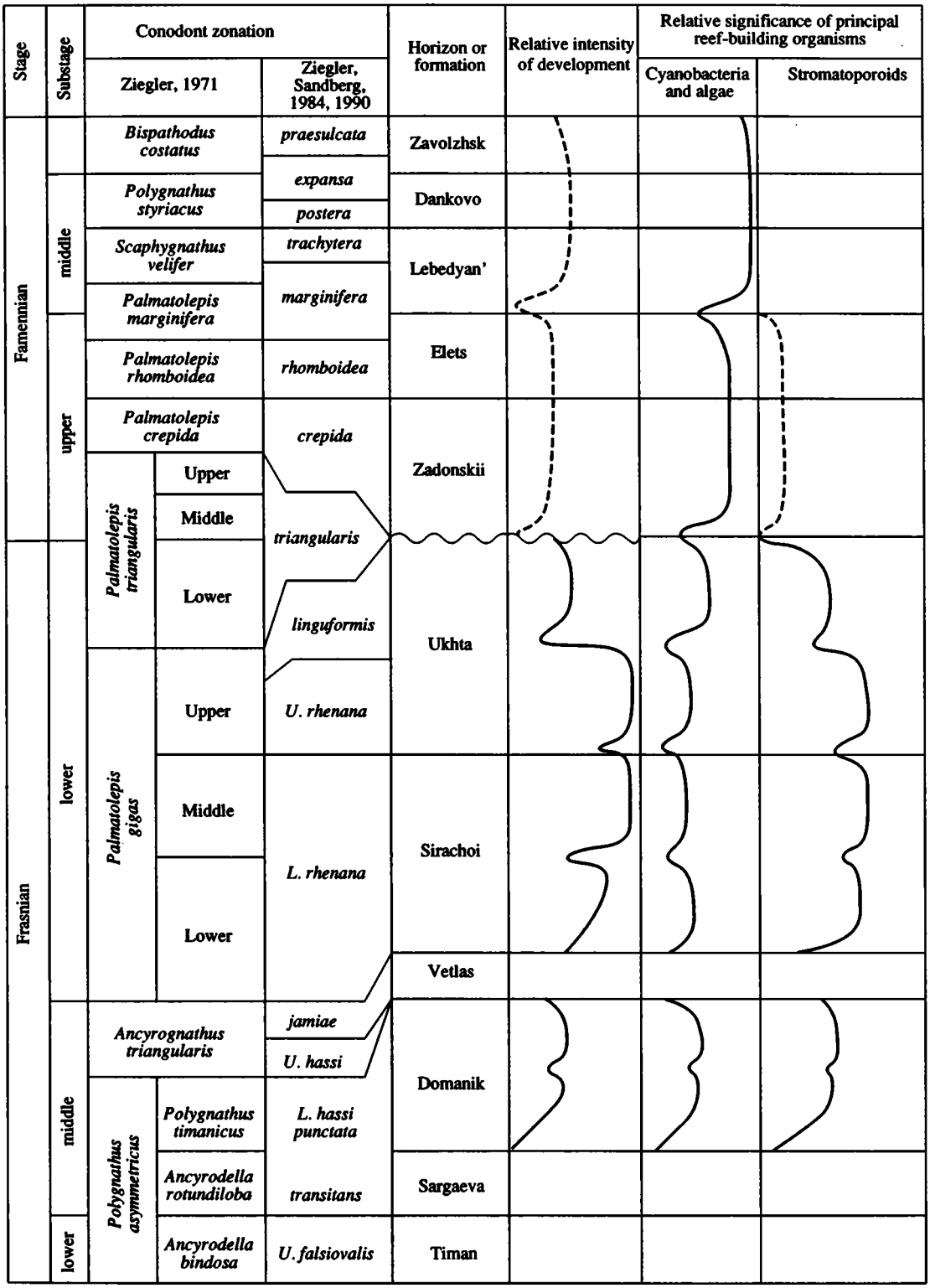

Fig. 2. Scheme of development of Upper Devonian reefs in the Timan–Pechora province (dotted lines denote presumable, undocumented intervals).

instance, Menner (1989, pp. 89 and 98) reported on occurrence of lower Famennian algal–stromatoporoid rudstones in the Sandivei and Bagan areas.

The precise level, at which the Frasnian stromatoporoid reefs give place to Famennian algal–cyanobacterial deposits, can be defined only in a continuous succession of reefal facies studied in detail. Sections of this kind are unknown in the region, because the Ukhta Formation top (the terminal Frasnian) is characterized by a hiatus, and what facies, reefal or non-reefal have been eroded, is unknown. For instance, in some sections of the Khar'yaga and Komandishor areas, reef massifs are overlain by carbonate and clayey-carbonate variegated deposits of the uppermost Frasnian. Similar sections are known as well in the northern Khosedayus, southern Syurkharata, and Olen'ya areas of the Khoreiver depression, and they can be interpreted as reflecting a local break in sedimentation. Alternatively, they may imply the regional cessation of reef-forming processes by the end of the Frasnian Stage, and this explanation seems more reasonable, because the indicated sections occur in different structural zones.

There are also more direct indications in favor of the last conclusion. Menner, who studied carbonate deposits in the north of the Uralian foredeep, reported: "the reefal sequence of the uppermost Frasnian is lacking bioherms in this area. Stromatoporoid–algal biostromes occurring here are intercalated with laminated limestones. The overlying sequence of Frasnian–Famennian boundary beds ... is distinguishable in exposures owing to predominance of flaggy laminated sediments. Prevailing among the latter are oolitic, oolitic-grumous, and clotty limestones, which enclose interlayers with fragments of undeformed structures produced by blue-green algae, microphytoliths of red algae, *Renalcis* aggregates, and shell detritus. Organogenic stromatoporoid–algal biostromes are rare" (Menner *et al.*, 1991b, p. 133).

Thus, the direct and indirect indications imply, despite a dual meaning of the later, that reef development in the region was significantly reduced by the end of the Frasnian stage. The period of reduced reef formation was likely short, spanning the second half of the late Ukhta time. In addition, stromatoporoids have not been encountered in reefal and non-reefal limestones of many upper Frasnian sections (Bol'shaya Syn'ya monocline, Bolshezemel'skaya Tundra uplift, and other areas), and this indicates their absence or extreme rarity rather than a result of careless observations.

Volga–Urals Region and Western Slope of Central to Southern Urals

By the end of the 1950s, the Upper Devonian buried reefs were recovered in both regions in the course of prospecting works for oil and gas. M.M. Grachevskii, who regarded the peculiar Kama–Kinel' depression as a sediment-uncompensated basin, rightly suggested possible occurrence of Devonian reefs along its periphery. I.A. Antropov distinguished corresponding reefal facies in core sections and obtained first data on their lithological and paleontological characteristics. In the western slope of central to southern Urals, reefs have been recognized earlier, and their composition, biota, tectonics, and paleogeography were studied in the early 1950s (Domrachev, 1952; Chochia, 1955).

Within the Volga–Urals region, development of late Frasnian reefs commenced in the Mendym time (Lower *Palmatolepis gigas* Zone) and was most intense during the Voronezh, Evlanovka, and Livny periods (Fig. 3). Three morphological–paleogeographic groups of Upper Devonian reefs can be distinguished in this region.

First, this is a system of asymmetric reefs around the Kama–Kinel' depression. These reefs with steep slopes (20–30°) raise for few dozens of meters above sediments deposited in their landward side and much higher, for few hundreds of meters, above basinal sediments of the Kama–Kinel' depression. Sedimentary facies on opposite sides of reefal massifs are contrast: reef rocks grade landward into the shallow-water carbonate deposits bearing diverse benthic fauna, and seaward they are replaced by fore-reef breccias and then by deep-water bituminous-siliceous and clayey-carbonate deposits of the Domanik type, which yield sponge spicules, radiolarians, and rare foraminifers. Younger reefs of the system usually migrated seaward relative to older ones, although some of them developed *in situ* and produced the upper Frasnian to Famennian (Zavolzhsk Horizon inclusive) or to lower Famennian reefal sequences (Mirchink *et al.*, 1974). Buildups of the other type, which represent outer and inner reefs of the past basin, are quite thick (up to 500–550 m) and more or less symmetric in cross section. In the Kama–Kinel' depression, they are surrounded by basinal deposits (e.g., the Karacha-Elagino, Yarino-Kamenolog, Ozernyi, and Bastryk reefs) and correspond in morphology to domelike buildups and atolls. Stratigraphic range of these buildups corresponds to either the upper Frasnian (Chermasan reef), or the upper Frasnian–Famennian (Bastryk reef) intervals. Buildups of the third type set inside shallow-water deposits are less thick (from 50–80 to 100 m), connected with the Bashkir, Tatar, and Perm'–Udmurtia paleoswells. Their individual areas are less than 2–2.5 km in diameter, although they may span the same stratigraphic intervals (Mirchink *et al.*, 1974; Trokhova, 1991).

During the Mendym stage of reef development, principal reef-builders were aggregates of cyanobacteria *Girvanella* and *Coactilum* in association with less abundant *Rectangulina, Chabakovia, Renalcis, Izhella,* and red alga *Solenopora.* They all coexisted with tabulates, bryozoans, and brachiopods during the second half of the stage. During the main period of reef formation in the Voronezh, Evlanovka, and Livny time, reefal communities included diverse cyanobacteria (*Chabak-*

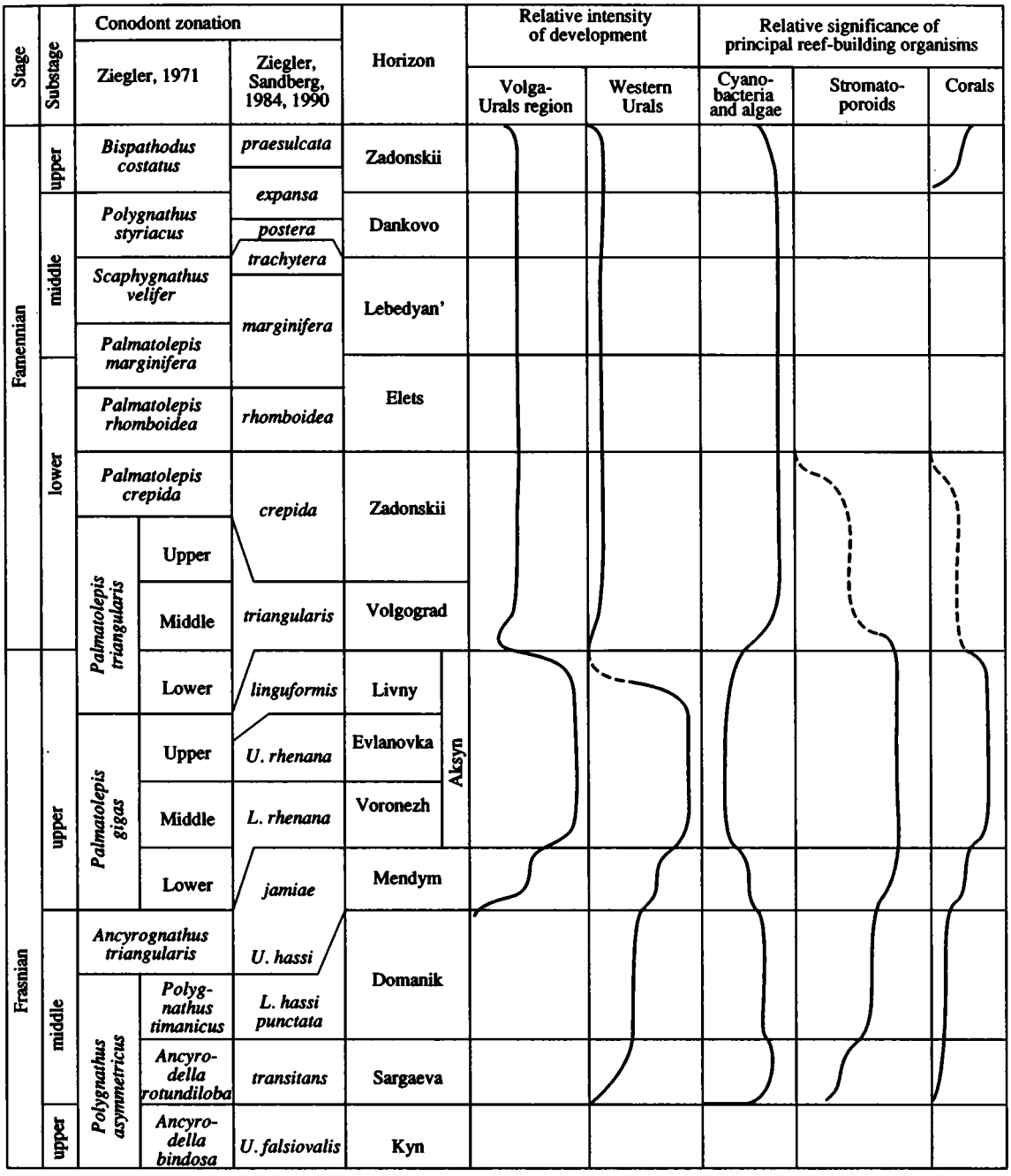

Fig. 3. Scheme of development of Upper Devonian reefs in the Volga–Urals region (dotted lines denote presumable, undocumented intervals).

ovia, Renalcis, Izhella, Epiphyton), red (*Solenopora, Parachaetetes*) and green (*Rhabdoporella, Dasyporella, Sphaeroporella, Kamaena*) algae, stromatoporoids (abundant *Amphipora*), tabulates, rugoses, bryozoans, and crinoids.

Communities of reef-building organisms changed in the Famennian Stage of reduced development of reefs, which are represented by cyanobacterial–algal-foraminiferal buildups. Oncolitic grumous and patterned limestones of the latter yield remains of cyanobacteria (*Girvanella, Shuguria, Renalcis, Izhella*), green (*Rhabdoporella, Sphaeroporella, Issinella, Dasyporella, Kamaena*) and red (*Solenopora, Parachaetetes*) algae, foraminifers, and of less abundant corals, bryozoans, and crinoids. A.A. Trokhova reported on occurrence of stromatoporoids in lower Famennian reefal beds, in which stromatolitic and oncolitic rocks are widespread.

The Upper Devonian reefs of the Volga–Urals region are frequently dolomitized, to a great extent sometimes.

Specific Famennian buildups, which are almost lacking the frame-forming organic remains, have been interpreted once as non-reefal in origin (Shuiskii, 1981) and attributed to "organogenic massifs of a peculiar type" (Korolyuk *et al.*, 1975). Most likely, they represent a group of frameless reefs (Kuznetsov, 1996b, 1966c). R. Ginsburg, the well-known expert on lithology of reefs and carbonate deposits, suggested to term these specific buildups as "framework least" (personal discussion with him in 1977).

In western slopes of the central to southern Urals (Fig. 3), development of reefs commenced in the Sargaeva time (Middle *Polygnathus asymmetricus* Zone of the international conodont scale or local *Ancyrodella rotundiloba* Zone). The middle Frasnian buildups yield here remains of diverse cyanobacteria, green and red algae, stromatoporoid colonies, rare solitary or colonial rugoses and tabulates (*Tabulophyllum, Peneckiella, Striatopora, Aulopora, Syringopora, Alveolites*, and others).

The initial late Frasnian time was a period of the bottom relief differentiation and greater development of corals. Organic remains representing reef-builders of the Mendym time are cyanobacteria (*Girvanella, Coactilum, Shuguria, Epiphyton*), red (*Solenopora*) and green (*Issinella*) algae, massive and branching stromatoporoids, solitary and colonial corals, foraminifers, crinoids, brachiopods, and some others. The development of reefs was most intense in the second half of the late Frasnian (in the Askyn or Voronezh– Evlanovka–Livny time), when reefal buildups as thick as 400 m and more have been created. These reefs contain "the exceptionally diverse assemblage of abundant foraminifers, corals (tabulates and rugoses, V.K.), stromatoporoids, crinoids, bryozoans, brachiopods, pelecypods, gastropods, goniatites, ostracodes, and trilobites" (Chochia, 1955, p. 256). According to Chuvashov (1968), the associated taxa were cyanobacterial stromatolites (calcibionts *Girvanella, Coactilum, Izhella, Shuguria, Epiphyton, Chabakovia, Renalcis*), green (*Dasyporella, Issinella, Cateniphycus, Litania, Nodosinella, Rhabdoporella, Wetheredella*) and red (*Katavella, Solenopora, Tubomorphophyton*) algae, and charophytes (*Umbella*). It is important that frame-forming organisms coexisted in this case with sedentary foraminifers (*Paraturammina, Cribrospheroides, Uralinella, Ivdelina*, and other genera). In distinction from other researchers, Chuvashov surprisingly believed that upper Frasnian reefs were built by algae with a minor contribution of skeletal stromatoporoids and corals.

The distribution area of Famennian reefal facies is reduced, and development of reefs likely declined at that time. Famennian reefs are mostly composed of cyanobacterial and algal dolomitic limestones. The corresponding reef builders coexisted with abundant foraminifers, rare brachiopods, gastropods, ostracodes, large echinoids, and corals (Chochia, 1955, p. 259). According to Chuvashov (1968), other remains present in the reefs are stromatolite-forming *Girvanella* and *Shuguria*, green algae *Nodosinella* and *Issinella*, problematic dasycladacean genera *Sphaerella* and *Asterosphaera*, and abundant charophytes. In lower Famennian strata of the Ufimian amphitheater, he also found *Amphipora* remains and massive stromatoporoids.

Materials considered above show that there is no principal difference between faunal and floral assemblages from the Volga–Urals and West Uralian regions. Accordingly, the comparable evolutionary trends characterize reefs of both regions.

The level between Frasnian framework reefs and Famennian frameless buildups cannot be unambiguously defined in the regions under consideration. Chuvashov and Trokhova reported that stromatoporoids, tabulates, and rugoses occur in lower Famennian strata of both regions, though their abundance rate remains unclear. At the same time, there are sections, in which remains of these organisms disappear much lower. For instance, section of the well-known Askyn Reef includes four members of upper Frasnian deposits. Two lower members are thick-bedded or massive, composed of reefal limestones with remains of stromatoporoids, receptaculites, tabulates, and rugoses. In contrast, two upper members of laminated non-reefal limestones are barren of stromatoporoids and rarely yield rugose remains (Domrachev, 1952, pp. 83–84).

Volga River Lower Courses

First data on reefs buried along periphery of the Caspian depression were obtained in the early 1960s. At present, over 20 oil-and-gas deposits confined to these reefs are known in the Saratov and Volgograd areas, where reefal buildups are penetrated by boreholes and their distribution patterns are elucidated. Having core sections, which are often incomplete, it is difficult however to study reefs and to establish with necessary details their paleontological characteristics and formation periods.

Available geological records imply that development of Frasnian reefs in the region commenced in the Sargaeva time and lasted until the end of the stage. At least five intervals of reef formation are distinguishable here: the Sargaeva, Semiluki, Bureg (Alatyr), Voronezh, and Evlanovka–Livny phases. Distribution of corresponding reef systems is elucidated between the Saratov and Kamyshin latitudes. In the right-bank area of Volga River, reefs are situated along margins of the Umet–Linevka, Shalino–Balandinka, Volzhskii, Voskresenka, Teplovka, and other depressions, which open to the east and southeast toward the Caspian lowland. Western and northwestern margins of reefs are in contact with shallow-shelf deposits, and their opposite sides face the deep sedimentary basin. For instance, these are Zhirnovka, Nizhnyaya Dobrinka, Novoe Korobkino, Kotovskii, and some other reefs. Younger reefs are usually advanced toward the basin and discon-

nected. Their thickness is insignificant, and only some of them are up to 100–120 m thick (Kotovskii Reef of the Evlanovka–Livny phase). Sections of some others, which developed longer, span the Sargaeva–Semiluki, Alatyr–Voronezh, and Voronezh–Evlanovka–Livny intervals. These can be up to 450–500 m thick (Novoe Korobkino Reef of the Alatyr–Voronezh period).

Reefs of the other type are solitary, isolated, and relatively symmetric in cross section. These are the Dem'yanka, Ovragi, Petrovka, Liman–Grachevka, and some other reefs, which developed long, as a rule. For instance, the Slyusarevo Reef developed since the Rudkino (early Sargaeva) until the Livny time inclusive. Accordingly, reef of this type are thicker than others (300–400 to 500 m).

It is important that the asymmetric reefs bear fossils of the Uralian aspect, whereas related back-reef facies yield faunal remains of central regions. It is possible to suggest therefore that depressions indicated above, in particular, the Umet–Linevka depression, represented gulfs of the Caspian microocean and were connected via this seaway with the Uralian paleoocean. The isolated reefs of the Ovragi and Petrovka type did not block communications between the gulfs and microocean.

Among most important builders of Frasnian reefs, there were cyanobacteria (*Shuguria, Girvanella, Epiphyton*), diverse algae (coralline taxa included), various stromatoporoids (*Amphipora, Stromatopora, Stachyodes, Paramphipora*), tabulates (*Syringopora, Alveolites, Cladopora*), and less abundant rugoses (*Thamnophyllum, Tabellaephyllum, Phillipsastrea, Disphyllum, Neostringophyllum*).

As stated above, cessation of reef formation in separate areas is recorded at different levels of the middle–upper Frasnian sequences. Most significant among them are terminal levels of the Semiluki, Voronezh, and Evlanovka–Livny periods. The last one marks in addition a considerable break in carbonate sedimentation of any type, because the upper Frasnian carbonate deposits are overlain everywhere in the region by the terrigenous Umet–Linevka (basal Famennian) sequence of clay and calcareous clay beds.

The Kotovskii Reef studied in detail exemplifies an interesting feature of the terminal Evlanovka–Livny stage of reef formation. The oldest northern part of the reef is built of stromatoporoid, algal, and cyanobacterial remains. During the next phase of reef formation that developed southward of initial locality, stromatoporoids almost completely disappeared among reef-building organisms, and algal–cyanobacterial community became dominant. In other words, development of framework reefs gave place to evolution of frameless bacterial–algal buildups during the Evlanovka–Livny period.

Data on Famennian reefs of the region are limited and less detailed, especially with respect to exact stratigraphic ranges of corresponding reefal deposits. They are described in general terms as components of the Famennian–Tournaisian system of asymmetric reefs. Taking into consideration the terrigenous composition of the Linevka–Umet (lower Famennian) sequence, it is possible to suggest that this stage of reef formation commenced somewhat after the earliest Famennian time. In the right-bank area of Volga River, the Famennian–Tournaisian reef system is localized within the marginal zone of the circum-Caspian depression, i.e., it is displaced seaward relative to the older one because of a considerable widening of shallow shelf zone behind the reefs. The slope-break line and associated reef system of the middle–late Frasnian, which were of undulating configuration and represented a system of interconnected depressions (gulfs), got the nearly linear smooth outline, because the depressions turned out to be filled in with clay and calcareous clayey deposits before the incipient Famennian time. Simultaneously, the development of Famennian reefs advanced into the northwestern and northern peripheral zones of the circum-Caspian depression. Summary sequences of Famennian–Tournaisian reefs are up to 700 m. Their rocks are dolomitized to a variable extent, and reef-building organisms are inadequately known. Principal among the latter were cyanobacteria (*Shuguria, Ulalinella*), and green algae (bereselliids). Other organic remains are represented by oncolites, coral and bryozoan fragments, brachiopod shells, foraminifers, and ostracodes. Unfortunately, these reefs have not been studied in paleoecological aspect, and role of frame-building organisms (corals and bryozoans) remains unclear.

West Canadian Basin

Natural exposures of Upper Devonian reefs are known in the West Canadian basin and Rocky Mountains surrounding it. These well-studied reefs are overlain by younger deposits and represent host rocks of important oil-and-gas deposits (*Mineral Deposits...*, 1969; Moore, 1988).

Devonian sequences of the basin are subdivided into a series of local stratigraphic units (formations), age relationships between which are intricate sometimes. The generalized regional sequence of uppermost Middle to Upper Devonian deposits is shown in Figure 4. It spans three large sedimentary cycles, the lower two corresponding to a period of vast transgression. The Beaverhill Lake Group (upper Givetian–lower Frasnian) and lower beds of the Cooking Lake Formation characterize deposits of the oldest cycle, when the Peace River arch represented a shoal that accumulated sediments of the Slave Point Formation. Rocks of the latter either grade into, or underlie reefs of the Swan Hill Formation. According to the conodont scale, stratigraphic interval of these reefs corresponds to the Middle–Lower *Polygnathus asymmetricus* zones.

Two reef arcs, which surround the Peace River arch, developed during a period of gradually advancing

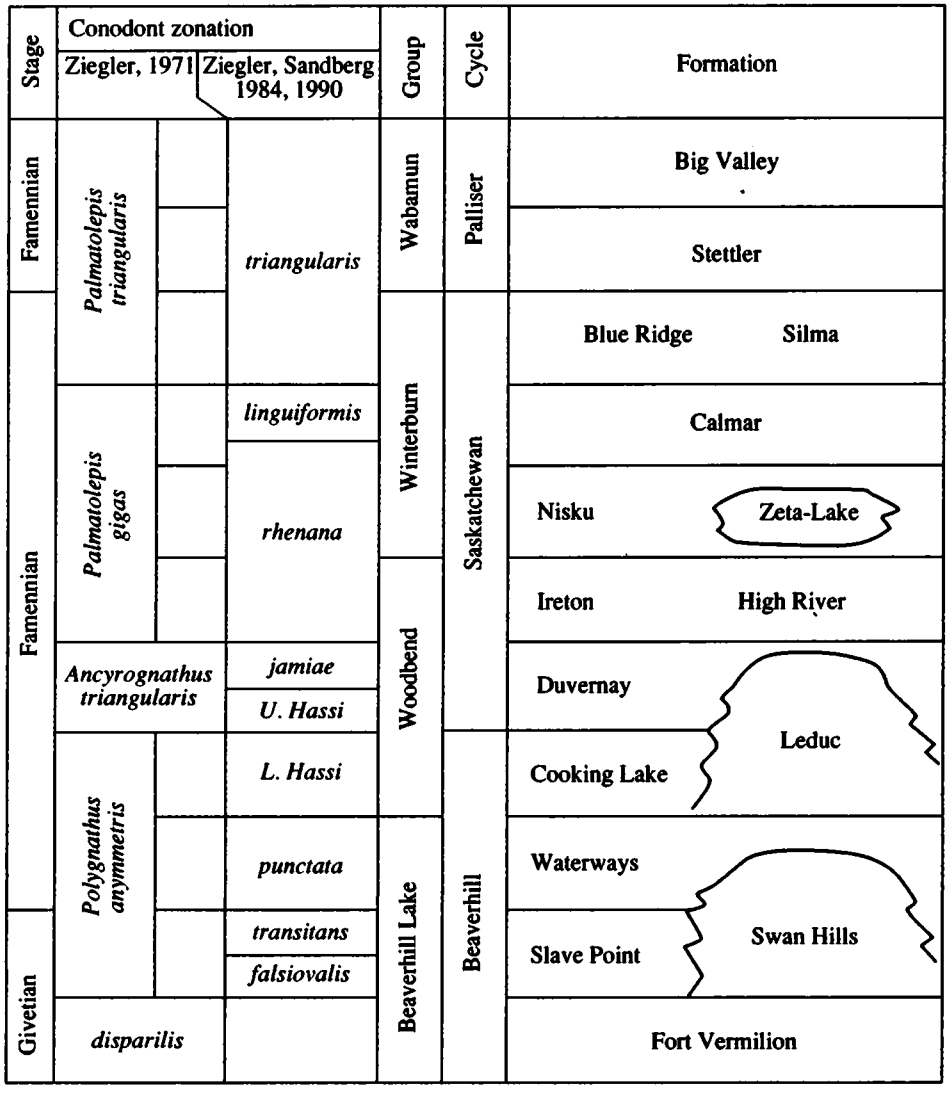

Fig. 4. Stratigraphic position of Upper Devonian reefs in western Canada.

transgression. Upper Givetian reefs constitute the outer arc, and younger lower Frasnian buildups, which locally may span the middle substage, are structures of the inner arc (the latter are included in the next cycle). The oldest cycle terminated with accumulation of the clayey Waterways Formation and lower clayey–calcareous deposits of the Cooking Lake Formation that is attributed to the Woodbend Group. As a rule, the reefs of the region represent the flat-topped, rather isometric buildups having diameter of few dozens of kilometers (the Judy Creek Reef is 50–60 km across) and thickness up to 50–60 m. The area/thickness ratio implies that these were sizeable shoals that accumulated biogenic carbonate deposits, including framestones produced by *Amphipora*. Desiccation marks and tidalites are recorded at several levels in their sections. Reefs with typical facies zoning, i.e., those with fore-reef, reef-flat, and other characteristic sediments, developed along shoal edges, which faced the deep basin areas. In general, buildups of this kind fit the definition of "isolated carbonate platforms" in currently accepted terminology.

The next Saskatchewan cycle characterizes further development of transgression, during which deep-water clayey or clayey–calcareous sediments accumulated almost everywhere in the West Canadian basin. The Peace River arch raised above them like a sizeable island. The shallow shelf along eastern periphery of the basin represented accumulation site of carbonate sediments. A similar shelf in the south and southeast was wider, and carbonate deposits associate here with evaporites especially characteristic of the Grosmont Plateau. Frasnian reefs of the Saskatchewan cycle are exposed in the Rocky Mountains westward of the basin and along its eastern and southern periphery. Many middle Frasnian reefs of the central Alberta Province

are buried in the so-called West Pembina basin that separated the Peace River arch from the southern shelf zone. All the reefs represent the Leduc Formation that is concurrent in age to deeper-water deposits of the Cooking Lake (upper portion), Duvernay, and some other formations (Upper *Polygnathus asymmetricus–Ancyrognathus triangularis* zones).

In the southeast of the basin, reefs overlap carbonate deposits of the Cooking Lake Formation. The well-known Rimbey–Leduc–Clyde system or Rimbey–Meadowbrook trend of reefal massifs extends southeastward from the southern carbonate shelf to the Grosmont Plateau. It includes the Homeglen-Rimbey, Westerose, Bonnie Glen, Wizard-Lake, Glen Park, Leduc-Woodbend, Golden Spike, Acheson, and Clyde reefs. Southeastward of this chain, there is one more trend of the Bashaw, Malmo, New-Norway, and Duhamel reefs. Isolated Hilliard, Willington, Stettler, Redwater, Fenn-Big Valley, and Erskine reefs, which are situated between the Rimbey–Clyde trend and shelf zone, are of the cupola-shaped, flat-top (platform), and atoll-like types. Most of them are elongated, ranging in size from 1.6×5.3 to 10×22 km. They are 250–300 m thick and raise above conjugate non-reefal facies for 170–200 m. Among more isometric reefs, the greatest one is Redwater Reef having shape of equilateral triangle with sides 35–44 km long.

To the south and southeast of the main chain of reefal massifs, there are the Harmattan, Strachan, Ricinus, Stron, and some other reefs of the Leduc Formation, which are situated in piedmonts of the Rocky Mountains. In the northwestern part of the region, concurrent reefs frame the Peace River arch on the south and southeast. Some of them rest directly on the Precambrian basement locally covered with feldspar sandstone, while others are separated from the basement by thin beds of carbonate deposits. These are flat-topped and the atoll-like Worsley, Nordmandville, Gold Creek, and Sturgeon-Lake reefs. They are rather large; for instance, the latter is about $20–25 \times 45–50$ km in size. Between the considered areas, reefs of the Leduc Formation overlap, like in the southeast, the carbonate deposits of the Beaverhill Lake Formation. Drilling recovered here the buried Simonette-Bigstone, Colt, Fir, and some other reefs. Reefs of the Leduc Formation and concurrent deposits of the Duvernay Formation are overlain by clay of the Ireton Formation.

The Nisku and Wabamun formations terminating the Frasnian interval of the sequence are composed of regularly bedded carbonate sediments. Local biostromes and small bioherms buried in the latter are lacking positive relief forms.

Many reefs of the West Canadian basin are dolomitized strongly or even completely. They are of little use for paleoecological analysis and determination of reef-building and reef-associated organisms. However, other exposed or buried reefs are well studied in these aspects. They show that massive, lamellate, and branching stromatoporoids of the *Amphipora–Stachyodes* group associated during the reef formation with rugoses *Disphyllum*, tabulates *Thamnopora*, sponges, receptaculites, and with cyanobacterial and other microbial communities, most abundant among which were representatives of the genus *Renalcis*. An important role of binding algae and cyanobacteria is recorded in Middle Devonian reefs of the Winnipegosis Formation of the Elk Point basin. Other important factors, which affected structure of reefs, were biotic erosion, bioturbation, and dolomitization.

Reefs of the third Palliser cycle developed in a basin of a reduced area and concurrent terrigenous and evaporite sedimentation. Carbonate deposits of the cycle enclose few reefal buildups (e.g., Crossfield and Nordmandville reefs) insignificantly prominent in bottom relief. Some stromatoporoids (labechiids) are distinguished among reef-building organisms of the corresponding period.

Thus, reefs of the West Canadian basin were formed during the late Givetian–early Frasnian and the middle to initial late Frasnian periods. Development of reefs completely ceased in the second half of the late Frasnian.

Devonian Reefs of the Canning Basin, Australia

The Canning basin in northwestern Australia is one of well-known and perfectly studied structures, where Middle to Upper Devonian reefs are widespread.

Referring to words of A. Wade who was one of first investigators of reefs in the region, Playford (1980, p. 814) wrote that they are "remands of an ancient barrier reef which flanked the shores of the mountainous country to the north." Later on, C. Teichert introduced the term "Great Devonian Barrier Reef" that is in general usage at present.

The Canning sedimentary basin that hosts Upper Devonian reefs is a largest structural element of western Australia and occupies area of about 500000 square kilometers. In the north and northeast, the basin is bounded by outcrops of Precambrian rocks of the Halls Creek and Kimberly provinces. The wide (up to 50 km) belt of Devonian reefal limestones extends along south-southwestern side of these exposures for a distance of about 350 km. It is possible as well that extending further, along western and northern slopes of the Kimberly massif, it may be connected with concurrent reefs of the Bonaparte Archipelago, thus being not less than 1000 km long. Reefal complexes include here the back-reef carbonate rocks of the Pillara and Nullara formations, reefs proper, and fore-reef slope deposits. The Fitzroy trough representing a deepest part of the Devonian basin is situated further to the south and southwest of the belt.

Chains of reefs flanked the back-reef carbonate platforms and isolated former shoals, the sites of carbonate sedimentation, which correspond to tectonic blocks of

Precambrian rocks inside the basin. Small reefal buildups are also known among shelf deposits. Relative to the basin floor, reefs raised up to 300–400 m, and basin walls very steep near the reef front (angles of 35°–40°) sloped much gentler, under angles of 5° and less, further downward.

Carbonate sedimentation in the shelf zone commenced in the second half of the Givetian Stage and lasted throughout the Frasnian period, when the Pillara Formation accumulated (Fig. 5). Formation of backstepping (migrating landward) reefs was initiated along the shelf edge in the Frasnian time.

The Frasnian–Famennian boundary in the belt is of unclear character: according to conodont zonation, it is conformable in the fore-reef facies, but the shelf and reef facies may be interrupted by local unconformities. Famennian reefs of the Windjana Formation, which clearly migrated with time seaward, are conformably overlain by the Devonian–Carboniferous boundary beds of the Fairfield Group.

Reef-building organisms of the Frasnian time were diverse, represented by cyanobacterial–algal group (*Renalcis, Sphaerocodium, Girvanella, Parachaetetes*, and *Solenopora* genera of columnar stromatolites), by spheroidal, massive, and lamellate stromatoporoids (genera *Stachyodes* and *Actinostroma* inclusive), and by corals (*Hexagonaria*), bryozoans (*Sphaerospongia* and *Striatospongia*), and receptaculites. Their Famennian assemblage is less diverse, consisting mostly of cyanobacterial stromatolites (*Renalcis* and *Spaerocodium*) and rare remains of corals and stromatoporoids.

The precise cessation level of Frasnian reef development can be substantiated by conodonts distribution in main formations of the basin (Veevers and Wells, 1961; Glenister and Klapper, 1966; Druce, 1976). Though conodonts are extremely rare in the reef and back-reef facies, all finds of these fossils imply the Givetian to lower–basal upper Frasnian stratigraphic interval of their host deposits, i.e., the summary range from the *Polygnathus varcus–Sch. hermanni–P. cristatus* zones (Glenister and Klapper, 1976) to the *Polygnathus asymmetricus* Zone–Lower *Palmatolepis gigas* Subzone (Druce, 1976). Conodonts are more abundant in the Sadler and Gogo formations of fore-reef, slope, and basinal deposits. In Figure 5 reproduced from work by Playford *et al.* (1989), these formations are shown as overlying one another, but authors consider them, like some other researchers (Veevers and Wells, 1961; Druce, 1976), as age equivalents of reefs. They are not younger than the middle Frasnian (Veevers and Wells, 1976) and span the range of *P. asymmetricus*–Lower *P. gigas* zones (Druce, 1976), which corresponds to the uppermost lower–basal upper Frasnian interval of stratigraphic scale accepted in Russia. In other words, development of reefs ceased in western Australia during the second half of the late Frasnian. I should mention in this connection that Veevers and Wells (1961) emphasized lithologic distinction of upper Pillar beds from conjugate deposits. Playford *et al.* (1989) also pointed, though indirectly, to the reef formation decline by the end of Frasnian time.

Elbingerode Reef Complex of Germany

Reef complexes Iberger and Elbingerode of the upper–central Harz, Germany, are studied in detail and elucidate important features of Middle–Upper Devonian reefs situated in foldbelts (Krebs, 1974; Fuchs, 1990; Weller, 1991).

Four stratovolcanoes, which raised for 400 m above surrounding sea floor, originated in the Elbingerode area of the Hercynian Rhine zone that was volcanically active during the Eifelian–early Givetian time. In a shallow zone near their tops, reefs and related fore-reef, lagoonal, and other types of sedimentation developed since the late Givetian until the terminal Frasnian time (Fig. 6). As a result, there has been formed the Elbingerode reef complex about 4.5 × 18 km in size. Groups of reef-building organisms were stromatoporoids (*Amphipora* and others), massive and less frequent tabulates (*Alveolitella, Alveolites, Scoliopora, Thamnopora*), solitary and colonial rugoses (*Disphyllum, Endophyllum, Frechastrea, Phillipsastrea*), crinoids, rare bryozoans, and abundant stromatolites. According to my observations in the Braunesumpf, Volkmarskeller, and Michaelstein areas, similarly important were enveloping algae and, maybe, cyanobacteria. First colonies of corals and crinoids appeared on separate blocks of volcanic agglomerates, carbonate intercalations of which produce hematite–magnetite–limonite ore. Rimming reefs begun to form approximately in the middle of the *Polygnathus varcus* Zone. Soon afterward, there were formed atoll-like buildups and true atolls, which developed until the time of the lowermost interval of the *P. asymmetricus* Zone. In the next period corresponding to *P. asymmetricus* and *Ancyrognathus triangularis* zones and characterizing a decline in development of reefs, frameless buildups of the oozemound type have been formed instead of atolls. At the time of the Lower *Palmatolepis gigas* Subzone, the reef formation stage corresponding to the First Kellwasser event ceased. Finally, the terminal stage of gradually declining reef formation is correlative with the Upper *P. gigas* Zone, because the uppermost *P. gigas* Subzone is lacking reefal deposits. The overlying pelagic facies of the Famennian Stage are also free of reef-related components.

SOME SPECIFIC FEATURES OF LATE DEVONIAN REEF FORMATION

Data on distribution and consecutive lithologic changes of reefal deposits, which are considered above, support the well-known concept of decline and cessation of reef-forming processes in the Late Devonian time. They also elucidate many important details characterizing development of reefs (Fig. 7):

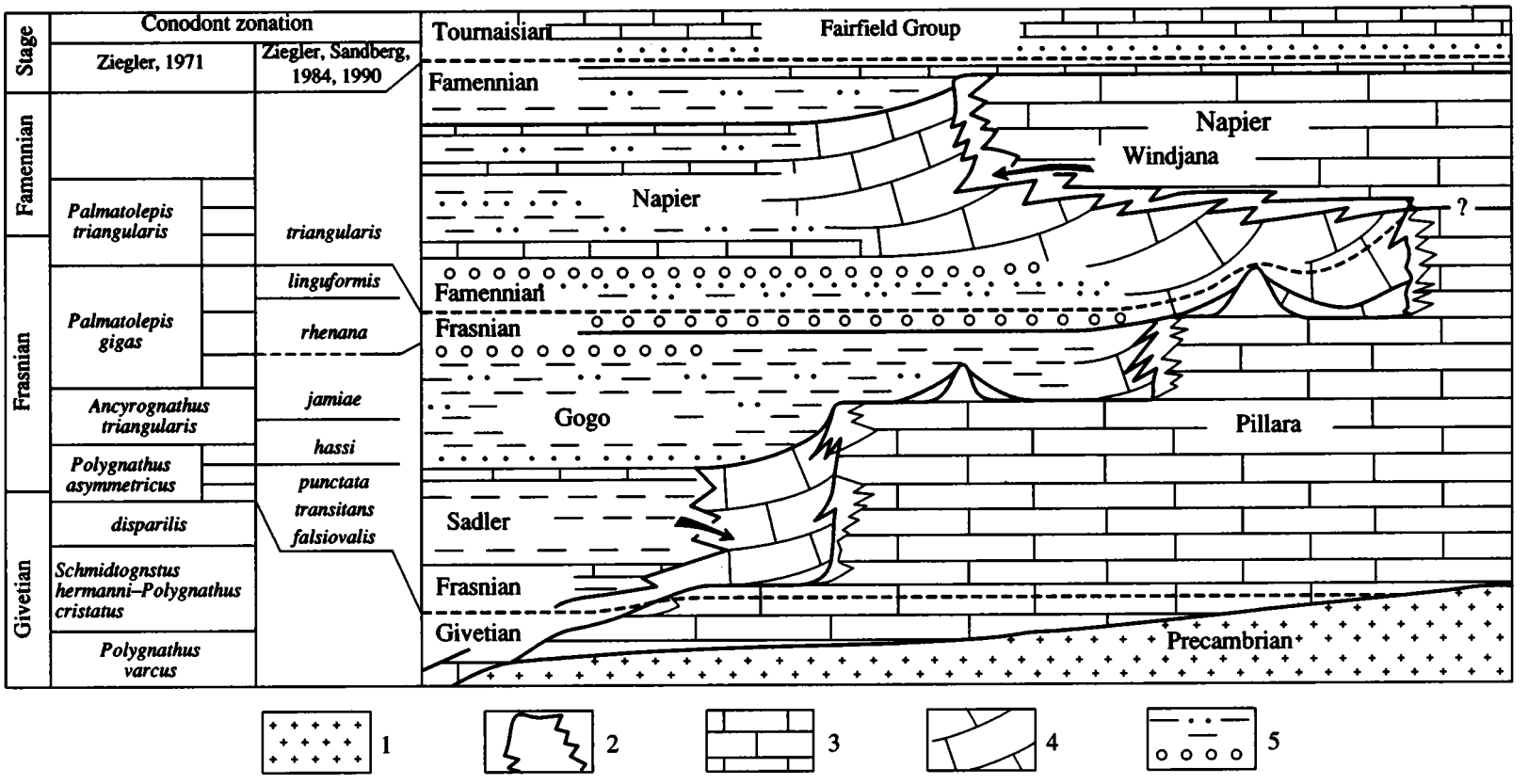

Fig. 5. Facies of Devonian reefs in the Canning basin, western Australia (after Playford *et al.*, 1980 with additions: (1) Precambrian basement; (2) reefs; (3) back-reef and (4) fore-reef carbonate facies; (5) terrigenous deposits.

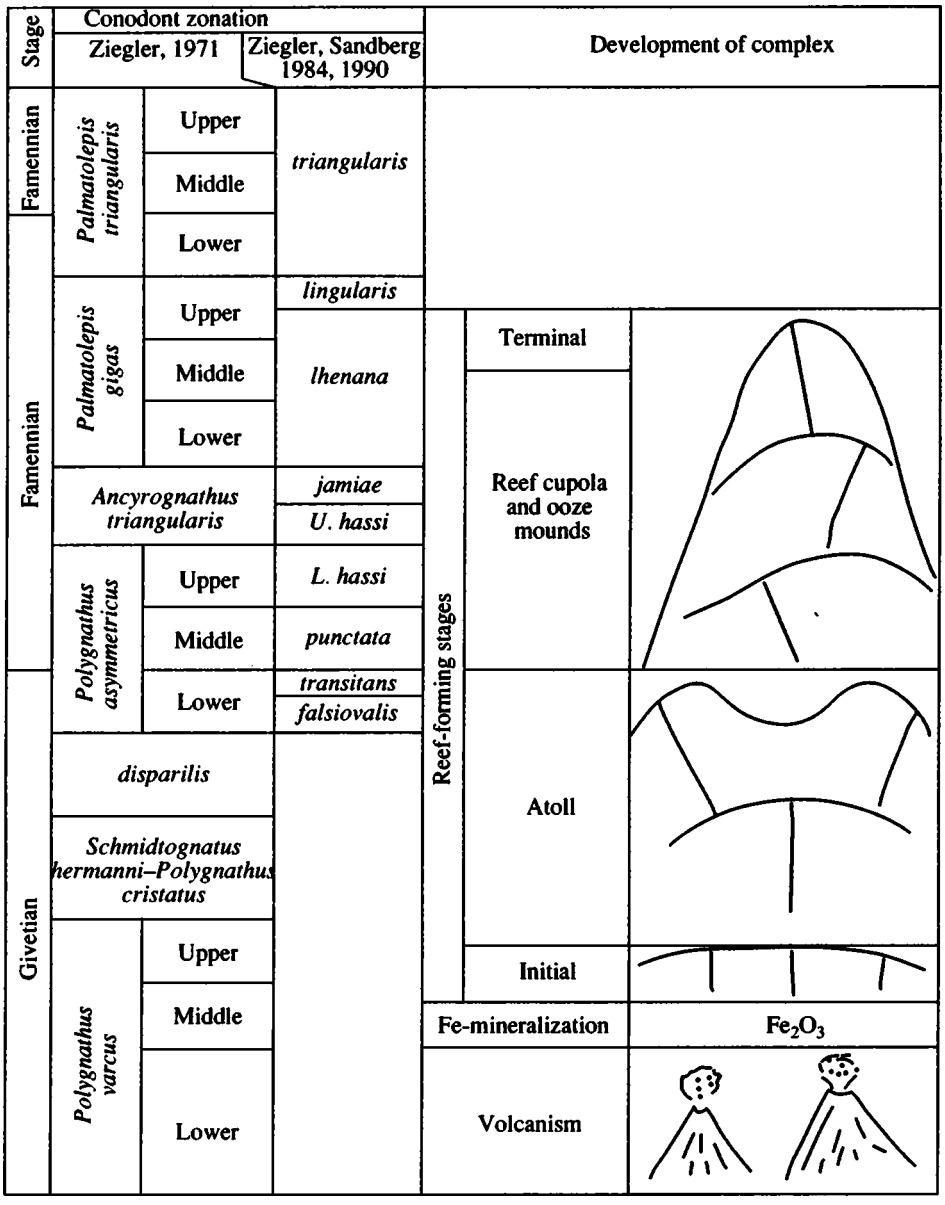

Fig. 6. Scheme of development of Elbingerode reef complex, Harz, Germany (modified after Weller, 1991).

(1) The decline of reef-forming processes was interconnected with changes in communities of reef-building organisms, which produced as a result different types of reefs. In general, the diverse fossil assemblages from Frasnian reefs include the following groups of taxa known from various regions: stromatoporoids (*Actinostroma, Amphipora, Clathrodictyon, Herronostroma, Labechia, Parallelopora, Paramphipora, Stachyodes, Striatopora, Stromatopora*), tabulates (*Alveolitella, Alveolites, Cladopora, Pachypora, Scoliopora, Syringopora, Thamnopora*), rugoses (*Disphyllum, Endophyllum, Hexagonaria, Macgeea, Neostringophyllum, Peneckiella, Phillipsastrea, Tabellaephyllum, Tabulophyllum, Thamnophyllum*), cyanobacteria (*Bevocastria, Coactilum, Epiphyton, Garwoodia, Girvanella, Izhella, Rectaguilina, Renalcis, Rothpletzella, Shuguria, Sphaerocodium*), green algae (*Cateniphycus, Dasyporella, Issinella, Kamaena, Litania, Maksimovia, Nodosinella, Palaeoberesella, Poncetella, Rhabdoporella, Sphaeroporella, Wetheredella*), and red algae (*Katavella, Parachaetetes, Solenopora, Tubomorphophyton*). Occurring less frequently are receptaculites, sponges, bryozoans, charophytes (*Umbella*), and stromatolites.

Famennian assemblages are much less diverse despite a similar generic composition and mostly consist of cyanobacteria and algae. As a result, the framework reefs of the Frasnian time turned to be replaced by Famennian frameless buildups of the ooze mound type.

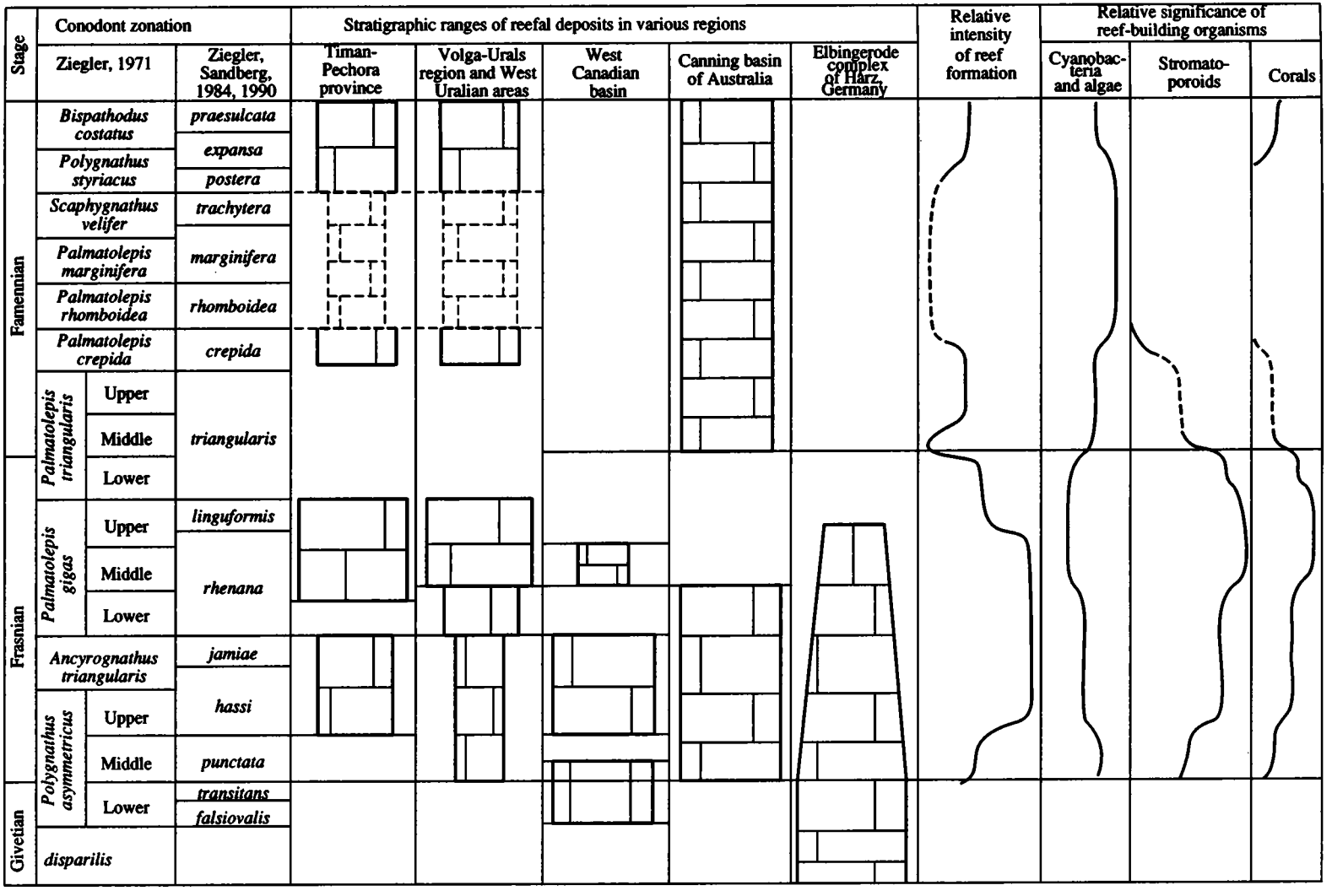

Fig. 7. Generalized scheme of Devonian reefs evolution (relative intensity of development corresponds to the width of columns; dotted lines denote imprecisely documented and presumable stratigraphic intervals).

(2) The Frasnian–Famennian boundary level just approximately marks transition from one reef type to another. Actually, cessation of development of framework reefs is recorded at three different levels at least.

In the West Canadian basin, Alazeya zone, Canning basin of Australia, Harz (Elbingerode reef complex), and Uralian foredeep (Timan–Pechora province), framework reef ceased to develop at the time of Upper or Middle *Palmatolepis gigas* zones, i.e., by the end of the Frasnian Age. In Canada, reefs of the Leduc Formation do not occur above the *Ancyrognathus triangularis* Zone, and buildups of the Nisku Formation (Middle *Palmatolepis gigas* Zone) are extremely rare, thin, and morphologically indistinct. Within lower courses of the Volga River, framework reefs developed until the end of the Frasnian Age. In the Volga–Urals region, Timan–Pechora province, and some Uralian areas, the weakened development of framework reefs lasted somewhat longer, because stromatoporoid and coral remains occur here in the basal Famennian reefal deposits. A new generation of frame-builders (corals) appeared only in the terminal Famennian time, but not everywhere (Volga–Urals province and some localities of the Urals). Famennian reefs known from the Canning basin and peripheral zone of the circum-Caspian depression are composed of other organic remains.

Thus, a period of transition from framework to frameless reefal buildups was short but not instant, and I doubt the idea that the main factor of corresponding changes in reefal biota was an astronomic catastrophe, i.e., the asteroid or giant meteorite impact that is thought to be responsible for the Kellwasser event and appearance of corresponding iridium anomaly. Almost everywhere, or at least in most cases, the decline of reef formation and disappearance of frame-building organisms were gradual. These biotic events lasted throughout the late Frasnian–early Famennian period, and their cessation is recorded at different stratigraphic levels in various regions that is incompatible with influence of any instant factor. As is actually established, at least 20 stromatoporoid genera, the most important builders of framework reefs from families Labechiidae and Actinostromatidae (genus *Clathrodition*) survived the crisis and contributed much to formation of Famennian reefs (Stearn, 1987).

(3) The development intensity of Frasnian framework reefs was lower than in the Middle Devonian and variable with time in different regions. As is mentioned above, these reefs ceased to develop before the terminal Frasnian time in western Canada, Harz, and Uralian areas. In eastern areas of the East European platform, where Givetian and lower Frasnian reefs are extremely rare, their development commenced at the time of the Middle *Polygnathus asymmetricus* Zone, and its peak period corresponded to the late Frasnian *Palmatolepis gigas* Zone.

Development patterns of Famennian reefs are less clear, because they are less widespread and worse studied. In addition, not all buildups of this age are classed with and distinguished as reefs. Some data suggest however that there were two, the early and late Famennian peak phases of reef development, which were separated by a certain decline of the process in the middle Famennian time. Cyanobacteria and algae, which were principal reef-building organisms of the Famennian Stage, coexisted with stromatoporoids and corals during the early phase and only with corals during the late one.

(4) Some similar features and certain distinctions characterize structures and development of reefs in the epicontinental and oceanic basins, although all principal reef types developed in both cases. For instance, the extended asymmetric reefal systems (barrier and marginal reefs) are known in the East European platform and Kama–Kinel' depression, on the one hand, and within the Brabant massif, on the other. Isolated reefs of internal basinal areas are exemplified by some buildups of the Timan–Pechora and Kama–Kinel' epiplatform areas and by those of the Ibèrger and Elbingerode reefal complexes, which originated in a sea that separated continental areas. Small reefs and other buildups of shelf zones are distinguished within the Tatar arch and in former shelf areas of the Canning and Brabant basins. In general, the thickness range of reefs originated in epicontinental and oceanic basins is comparable. They could be up to hundreds of meters thick in both cases like, for instance, the Givetian–Frasnian reefs of the Elbingerode complex (600 m), the upper Frasnian reefs of the Kyn–Chusovaya uplift of western Urals (400 m), or the Novoe Korobkino reef of the Alatyr'–Voronezh period (500 m) in lower courses of the Volga River.

The structural localization of reefs was however different. In epicontinental seas, they developed at slopes of epiplatform uplift and depressions, and along local anticlinal structures. In oceanic basins, reefs rimmed internal microcontinents and rigid blocks (Kazakhstan, Tarim, Brabant, and some others) or developed in volcanic arcs (reefs of the Harz, South Tien Shan, Dzhungar–Balkhash, and some other arcs). Accordingly, reefal deposits under consideration are interconnected with concurrent sedimentary facies of different types. In platform regions, the latter are represented by carbonate, bituminous-siliceous, and clayey-carbonate deposits, whereas facies associations of oceanic origin include volcanogenic-sedimentary, tuffite, and cherty formations. There is also a certain difference in morphology of reefs, which occupy larger areas within platforms, where bottom relief and tectonic movements were less contrast. Buildups of this type are often termed as bank reefs. Good examples are the Swan Hills (western Canada), West Vuktyl, Sandivei (Timan–Pechora province), and some other buildups.

In oceanic sectors, Frasnian reefs usually upgrade the Middle Devonian buildups, whereas in epicontinental seas, except for the West Canadian basin, where

Givetian reefs are rather widespread, they exemplify a separate stage of reef-forming process. Moreover, some well-studied sections show that formation of reefs in oceanic sectors tended to cease earlier than in epicontinental basins. This tendency is not universal however, because development of reefs in the West Canadian basin also ceased by the end of Frasnian Stage. It is likely that more active and contrast tectonic subsidence of oceanic floor provoked the earlier development of reefs and subsequent earlier cessation of the process.

Finally, the Famennian reefs have been formed mostly in platform areas (western Canada, where reefs of this stage are extremely rare, is again an exception). In oceanic sectors, these reefs developed on rigid continental blocks only (Brabant massif or Kazakhstan microcontinent, par example), whereas in volcanic chains associated with deep troughs, the isolated Frasnian reefs are buried under non-reefal pelagic deposits of the Famennian Stage. Buildups of this kind likely represented analogues of guyots and seamounds of present-day oceans.

I would like to emphasize however that above distinctions between reefs of epicontinental and oceanic basins are conventional rather than absolute. They reflect a tendency but not the strict discrimination criteria.

CONCLUSION

(1) The Late Devonian was an epoch of declining development of reefs, when their framework structures, which have been built by stromatoporoids, rugoses, tabulates, receptaculites, cyanobacteria, and diverse algae, gave place to development of reefoid cyanobacterial–algal buildups. To a first approximation, the change of reef types is confined to the Frasnian–Famennian boundary. The event was not instant, asynchronous in different regions, and lasted throughout the late Frasnian and early Famennian. Accordingly, it is difficult to accept idea that the turning point in development of reefs was interconnected with an astronomic event like the asteroid or great meteorite impact, and one should seek for geological reasons explaining that phenomenon.

(2) Reefs of epicontinental basins developed along their slopes and around internal uplifted blocks. They associate with concurrent carbonate, clayey-carbonate, and bituminous–siliceous sedimentary facies. In oceanic basins, reefs were situated along edges of microcontinents and lesser rigid blocks of inner zone and in particular volcanic chains. In this case, the concurrent deposits include terrigenous–carbonate, volcanogenic-sedimentary, and cherty beds.

(3) It is likely that reefs of oceanic sectors begun to form earlier than in epicontinental basins, since the Middle Devonian time, and that their development also ceased earlier, before the late Frasnian. Famennian reefs resembled guyots of present-day oceans and were widespread in platform areas but much more rare in oceanic sectors, where they were associated with structures of microcontinents.

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Lower Permian in the Vicinity of the Verkhneozernoe Village (Southern Urals)

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Abstract—One of the most complete sections of Permian deposits in the southern Urals is described. It spans the middle Asselian–Artinskian interval and yields fusulinids, ammonoids, and conodonts. The upper half of the Uskalyk Formation is shown to be correlative with the upper zone of the Asselian Stage. Ancillary evidence obtained is in favor of lowering the boundary between the Asselian and Sakmarian stages from the Kurmaya Formation top to its upper third at least. On the basis of ammonoids distribution, the boundary between the Sakmarian and Artinskian stages is shown to coincide with that boundary established in the Kondurovka section. In addition to the latter, the section under consideration can be recommended as the international boundary standard, i.e., the Global Stratotype Section and Point (GSSP).

Key words: stratigraphy, Permian, fusulinids, ammonoids, conodonts, southern Urals.

INTRODUCTION

One of the timely problem of the Permian stratigraphy at present is to refine ranges and boundaries of Permian stages and to establish the limitotypes, i.e., the Global Stratotype Sections and Points (GSSP), for each stage. A well-known section located near the Kondurovka Station in the Orenburg region, southern Urals, is most suitable one for establishing and fixing the lower and upper boundaries of the Sakmarian Stage. In recent years, the section has been actively studied under Chuvashov's leadership by a group of specialists from the Uralian Research Center (Chuvashov *et al.*, 1991; Chuvashov, 1999), and by V.I. Davydov in collaboration with researchers from the University of Boise, United States (Wardlaw *et al.*, 1999). As a result, particular levels appropriate for those stage boundaries were distinguished, though they are imperfectly substantiated, and there is a need to verify them with the help of other sections. Chuvashov recommended a section near the Verkhneozernoe Village that is located several kilometers to the south of the Kondurovka section. Pnev and Polozova (1981) managed to trace here the boundary between the Sakmarian and Artinskian stages, and our purpose was to refine its position and distinction criteria. It was also planned to establish the lower boundary of the Sakmarian Stage.

Unfortunately, it was impossible to perform all necessary field works because of insufficient funding, and we regard the results as preliminary ones. Nevertheless, the data acquired verify paleontological substantiation of stratigraphic units recognizable in the section and greatly supplement materials of Pnev and Polozova (1981) who described only the upper Sakmarian and Artinskian parts of the sequence. Fusulinid-bearing rock samples were collected from 28 levels of the Asselian–Artinskian interval, and 650 oriented thin sections were prepared to study them. Sixty samples ranging in weight from 1 to 3 kg were taken throughout the section for the conodont analysis. Conodonts were found in 12 samples (seven from the Uskalyk and Kurmaya formations, and five from Sakmarian–Artinskian boundary layers).

Fossils, we refer to below in this work, were identified by Leven (foraminifers), Reimers (conodonts), Leonova, Bogoslovskaya, and Boiko (ammonoids).

INVESTIGATION HISTORY

Khvorova (1961) was first to describe the Verkhneozernoe section, mainly its lithology. In their paper published in 1981, Pnev and Polozova proposed to regard this section as the reference one for the Artinskian Stage of the Urals. They described in detail the Artinskian part of the section and presented lists of foraminifers and ammonoids found in it. The lower Artinskian boundary that is of particular interest to us was placed at the base of Bed 6, where the appearance of fusulinids *Pseudofusulina livae* Shirinkina et Morozova, *P. pauli* Shirinkina and *P.* cf. *schellwieni* Vissarionova was established. The first and second species are *nomen nudum*, as they have been likely described earlier under other names in the paper by Shirinkina *et al.* (1980), which is devoted to lower Artinskian fusulinids from the Perm' region. Sakmarian fusulinids were

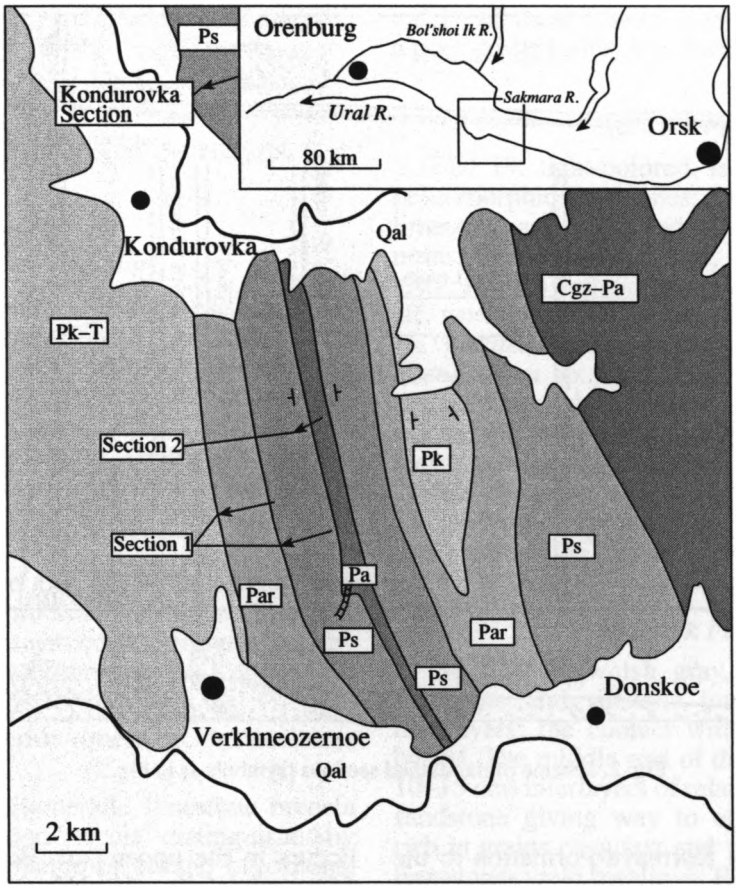


Fig. 1. Geologic scheme of the study region: (Cgz–Pa) Gzhelian and Asselian stages; (Ps) Sakmarian Stage; (Par) Artinskian Stage; (Pk) Kungurian Stage; (Pk–T) Kungurian Stage and Triassic; (Qal) Quaternary deposits.

identified at the level 60 m below Bed 6. The proposed boundary is undeterminable in ammonoid records. The nearest findings of these fossils were done in Bed 7, where they are represented by *Uraloceras* and *Agathiceras* forms indefinable at the species level and having a wide stratigraphic range. The first typical Artinskian species *Neoshumardites triceps* Ruzhencev was found only in Bed 14, i.e. 300 m above the boundary. Relying on these data, one can hardly establish a reliable position of the Artinskian lower boundary in the section under consideration.

Pnev and Polozova (1981) begun the section description from the upper part of the Sakmarian Stage, leaving aside the underlying deposits. A highly generalized column of the Verkhneozernoe section (from the Kurmaya to Aktasty formation) is presented in paper by Movshovich *et al.* (1979), in which conodont assemblages were characterized for the first time, and the lower boundary of Sakmarian Stage was assumed to be placed lower, at least in the middle of the Kurmaya Formation.

Nothing else, except for data mentioned above, is known about the section stratigraphy. At the same time, it is located only 10 km south of the perfectly known and well-studied Kondurovka section, being, as is shown below, highly competitive with the latter in completeness, abundance of fossils, and the rock exposure extent; in some parameters, it is even more interesting.

DESCRIPTION OF SECTIONS

We have described two sections in the vicinity of Verkhneozernoe Village. The first one approximately coincides with that described by Pnev and Polozova (1981), and the second route is located northerly (Figs. 1, 2).

Section 1 is located 3–4 km northward of the Verkhneozernoe Village, on the watershed between the Ural and Sakmara rivers. Intersecting it from north to south, there is a ridge with distinct topographic features, the doubled crest of which is composed of limestone of the Kurmaya and Sarabil' formations. In the western slope, the ridge is divided into a series of parallel watershed elevations gradually lowering in a westward direction. The latter are trending across the rock strike, and a normal succession of beds is well observable along their crest lines due to the better exposed rocks. Structurally, the described deposits, which span the range from the

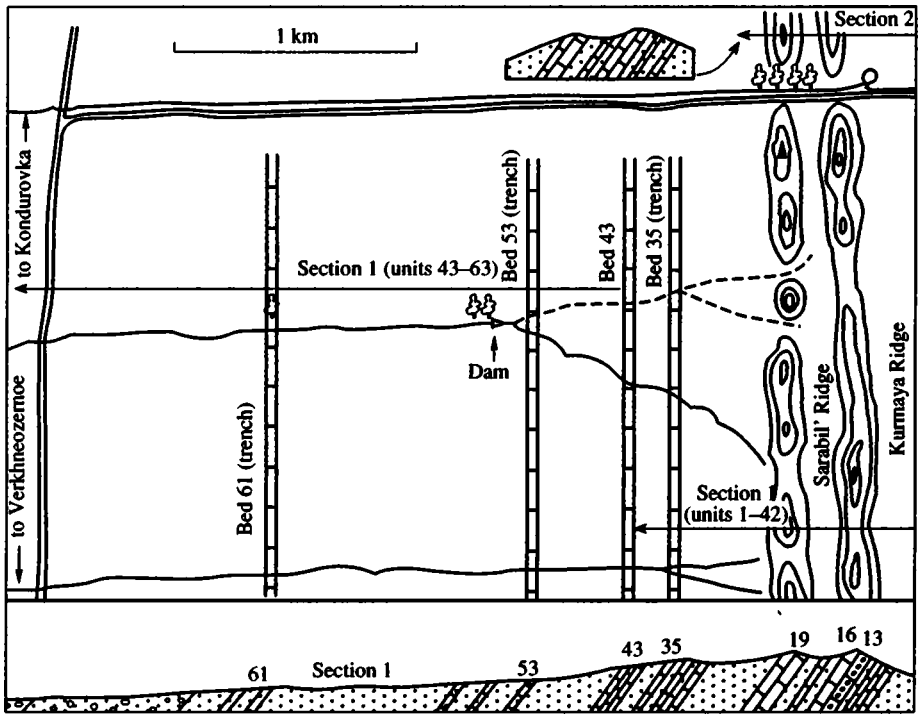


Fig. 2. Scheme of the studied sections (symbols as in Fig. 3).

Asselian limestone of the Kurmaya Formation to the Kungurian gypsum, form an ordinary monocline on the western limb of a major anticline trending north–south, the core of which is composed of terrigenous rocks of the Uskalyk Formation. Within the monocline, beds steadily dip westward at the angle of 55°.

The section description begins with the anticline core and continues westwards across the Kurmaya and Sarabil' limestone ridges and further along the watershed separating two creeks, the northern one crossed by a small dam (Fig. 2). Except for limestones of the Kurmaya and Sarabil' formations, other rocks are unsatisfactory exposed. The well-exposed are thin interlayers of more compact rocks, such as limestone, coarse-grained calcareous sandstone, and calcareous siltstone. They form distinct small ridges easily traceable along the strike. The main part of the section is composed of loose sandstone, siltstone and mudstone beds poorly exposed, and their nature can be figured out only based on local debris areas.

Uskalyk Formation

Rocks of the Uskalyk Formation are exposed in the anticline core. They characterize an upper part of this subdivision, in which the following beds are distinguished (from the base upward).

Bed 1: polymictic, fine-grained, silty sandstone. An interlayer (1.5 m) of aphanitic and detrital limestone with brachiopod fragments and crinoid columnals occurs in the upper part. Found conodonts represent *Mesogondolella* cf. *obliquimarginata* Chernykh; the thickness is 10 m.

Bed 2: rhythmic alternation of sandstone, siltstone, and sandy limestone; the thickness is 20 m.

Bed 3: dense micritic limestone, in places silicified; the thickness is 10 m.

Bed 4: graywacke sandstone, intensely weathered, with an interlayer of sandy fusulinid limestone; the thickness is 42 m.

Bed 5: sandy detrital and micritic limestone; the thickness is 10 m.

Bed 6: poorly-exposed section fragment with scattered fragments of fine-grained sandstone and siltstone; the thickness is 40 m.

Bed 7: sandstones alternating with sandy and micritic limestones highly silicified in places. Found in limestones are conodonts *Mesogondolella dentiseptata* Chernykh, *Streptognathodus elongatus* Gunnell, *S. simplex* Gunnell, *S. longissimus* Chernykh et Reshetkova; the thickness is 20 m.

Bed 8: alternating sandstone and sandy limestone with rare fusulinids (*Sphaeroschwagerina* sp.); the thickness is 15 m.

Bed 9: sandstone with three interlayers (1 m thick each) of compact, fine-detrital, silicified limestone; the thickness is 15 m.

Bed 10: sandstones alternating with siltstones and sandy fusulinid limestones; the thickness is 25 m.

Bed 11: sandstone with rare interlayers of micritic limestone; the thickness is 25 m.

Bed 12: loose sandstone and debris of micritic limestone; the thickness is 120 m.

The total incomplete thickness of the Uskalyk Formation is 352 m.

Kurmaya Formation

Bed 13: light gray, compact, fine-grained and pelitomorphic, medium- to thin-bedded limestones with chert lenticules and nodules; conodonts found near the top of the unit are *Neostreptognathodus* cf. *merrilli* (Kozur), *Mesogondolella parafoliosa* Chernykh, *M. simulata* Chernykh et Reshetkova, *Gondolella elegantula* Stauffer et Plummer, *G. donbassica* Kozitskaja, *Declinognathodus lateralis* Higgins; the thickness is 70–80 m.

Bed 14: Thick-bedded brecciated limestone with interlayers of laminated micritic limestone. The unit corresponds to the first breccia distinguished by Ruzhentsev (1951) in the section near the Kondurovka Station; the thickness is 15–20 m.

Bed 15: laminated micritic limestone; the thickness is 17 m.

Bed 16: massive conglomeratic limestone breccia corresponding to the "second breccia" distinguished by Ruzhentsev (1951). Fragments of corals, bryozoans, crinoids, and rare, mostly redeposited, fusulinid tests are encountered in breccia cement. Fusulinid taxa of the unit are *Pseudoendothyra* sp., *Eostaffella* sp., *Ozawainella* sp., *Pseudostaffella antiqua* (Dutk.), *Schubertella* aff. *kingi exilis* Sul., *Sch. paramelonica* Sul., *Pseudofusulinella* sp., *Triticites parvulus* Schellw., *Rugosofusulina* sp., and *Pseudofusulina paragregaria ascedens* Raus. Conodonts *Idiognathoides sulcatus* Higgins et Bouckaert, *I. sinuatus* Harris et Hillingsworth, *Streptognathodus ruzhencevi* Kozur, *S.* aff. *simplex* Gunnell, *S.* aff. *alekseevi* Barskov et al., *Declinognathodus lateralis* Higgins, *Mesogondolella longifoliosa* Chernykh, *M.* aff. *oliquimarginata* Chernykh were found near the bed roof in the fine-detrital limestone interlayer; the thickness is 3 m.

The total thickness of the formation is 100–120 m.

Karamurun Formation

Bed 17: frequent alternation of thin-bedded, pelitomorphic, marly, silty and sandy limestones with sandstone and siltstone; the thickness is 50 m.

Bed 18: thin-bedded, grayish brown, polymictic sandstone and siltstone with thin interlayers of more compact and lighter colored silty limestone; the number of interlayers increases upward. Interlayers of coarse-grained sandstone yield fragmented shells of cephalopods, brachiopods, and fusulinids in association with bryozoan remains and corallites. Unfortunately, all these fossils cannot be identified because of a poor preservation; the thickness is 80 m.

Sarabil' Formation

Bed 19: light-colored, laminated, fine-detrital and pelitomorphic limestones; interlayers of coarse-detrital limestone are composed of fragments of crinoid columns, bryozoan segments, algae, and rare fusulinid tests. *Pseudostaffella antiqua* (Dutk.), *Pseudofusulina* aff. *verneuili* (Moeller), *P. urdalensis abnormis* Raus., *Ps. urdalensis abreviata* Rauser. Redeposited *Pseudoendothyra* sp. and *Pseudostaffella antiqua* (Dutk.) are encountered near the unit roof in the interlayer of calcarenite and detrital limestone. Ammonoids *Agathiceras uralicum* (Karpinsky) and conodonts *Mesogondolella bisselli minuta* Chernykh and *M. striata* Chernykh were found in one of the samples from the upper part of the formation; the thickness is 110 m.

Malyi Ik Formation

Bed 20: brownish gray, polymictic, fine-grained sandstone and siltstone intercalated with mudstone interlayers; the contact with underlying limestone is buried. The middle part of the unit contains thin (up to 10–15 cm) interlayers of relatively compact, polymictic sandstone giving way to organic–detrital limestones rich in grains of quartz and volcanogenic rocks. These limestones yield fusulinids *Pseudostaffella* sp., *Palaeostaffella* sp., *Pseudothyra* sp., *Depratella* aff. *prisca* (Deprat), *Pseudofusulina* cf. *urdalensis* Rauser, *Ps.* aff. *gregaria* (Lee), and *Ps.* ex gr. *moelleri* (Schellwien). Moreover, they bear smaller foraminifers and unidentifiable fragmented skeletons of bryozoans, crinoids, algae, and goniatites; the thickness is 50 m.

Bed 21: poorly exposed interval of the section with debris of loose, fine-grained, polymictic sandstone and siltstone; near the top, medium- to coarse-grained compact thin-platy polymictic sandstones alternate with detrital limestone. Bryozoan and crinoid remains are distinguished in debris; the thickness is 73 m.

Bed 22: fine-grained sandstone and siltstone with rare interlayers of more compact sandstone; rocks are poorly exposed; the thickness is 60 m.

Bed 23: polymictic, medium- to coarse-grained, compact sandstone forming a distinct crest; the thickness is 3 m.

Bed 24: siltstone and mudstone; the thickness is 15 m.

Bed 25: calcareous, compact siltstone prominent in the relief; the thickness is 4 m.

Bed 26: poorly exposed interval with siltstone and mudstone debris; the thickness is 20 m.

The total thickness of the Malyi Ik Formation is 225 m. It is twice less thick and more than in the northerly section near the Kondurovka Station (Ruzhentsev, 1951; Rauzer-Chernousova, 1965). Such a great differ-

ence in thickness is hard to explain. It may reflect either the real thickness variation along the strike, or the uncertain positioning of the upper boundary. The Malyi Ik Formation differs from the overlying Kondurovka Formation in a lesser abundance of limestone interlayers in terrigenous rocks. Hence, it may be that we placed the boundary a bit below its position in the section described by Ruzhentsev. This is quite probable, because the Kondurovka Formation thickness is overstated in our section.

Kondurovka Formation

Bed 27: sandstone and siltstone grading toward the base into sandy-detrital limestone with bryozoan, gastropod, bivalve, brachiopod, crinoid, and red algae remains. Rare fusulinids are represented by *Eostaffella* sp., *Pseudostaffella* sp., *Rugosofusulina intermedia* Suleimanov, *R.* aff. *serata valens* Rauser, *R.* aff. *pulchrella* Rauser, *Pseudofusulina lutuginiformis* Rauser, and *Ps.* cf. *callosa proconcavutas* Rauser; the thickness is 14 m.

Bed 28: polymictic fine-grained compact sandstone alternating with siltstone; the thickness is 40 m.

Bed 29: compact light-colored pelitomorphic limestone; the thickness is 0.15 m.

Bed 30: fine-grained sandstone and siltstone with three interlayers of pelitomorphic limestone; the thickness is 12 m.

Bed 31: light-gray or yellowish pelitomorphic to fine-detrital limestone; the thickness is 1 m.

Bed 32: brownish gray, poorly laminated, fine- to medium-grained sandstone. Spheroidal coral colonies are typical; the thickness is 50–60 m.

Bed 33: pelitomorphic fine-detrital limestone; the thickness is 0.15 m.

Bed 34: fine- to medium-grained, poorly-laminated sandstone; the thickness is 35 m.

Bed 35: compact, banded, coarse-grained, polymictic sandstone alternating with sandy detrital limestone; fusulinids and bryozoans abundant here associate with rare brachiopods, crinoids, and bivalves. Assemblage of mostly redeposited fusulinids includes the following: *Pseudoendothyra* sp., *Neostaffella umblicata* (Putrja et Leontovich), *Wedekindellina uralica* (Dutkevich), *W. subovata* Safonova, *Parawidekindellina* aff. *kamensis* Safonova, *Aljutovella aljutovica* (Rauser), *Schubertella* cf. *kingi exilis* Suleimanov, *Fusulinella* cf. *paraschubertellinoides* (Putrja et Leontovich), *Fusulina* cf. *mjachkovensis* Rauser, *Montiparus* sp., *Rugosofusulina pristina* Kanmera, *R. pulchrella* Rauser, *Sphaeroschwagerina* sp., *Pseudofusulina lutuginiformis* Rauser, *Ps. sulcata* Korzhenevsky, *Ps. callosa* Rauser, *Ps. plicatissima* Rauser, *Ps. karagasensis karagasensis* Rauser, *Ps. karagasensis ventricosa* Rauser, and *Ps.* ex. gr. *moelleri* (Schellwien). Compact rocks of the unit are mined out for quarry stone, that is why there is a trench extending for several kilometers and favorable for observations along the strike. Having this opportunity, we may say with reasonable confidence that the unit corresponds to Bed 3 of the section described by Pnev and Polozova (1981); the thickness is 2 m.

Bed 36: fine-grained sandstone alternating with siltstone; the thickness is 50–60 m.

Bed 37: polymictic sandstone and siltstone, calcareous to a different extent and alternating with detrital limestone bearing bryozoans, crinoids, fusulinid tests (*Pseudofusulina* cf. *callosa* Rauser), and ammonoids *Andrianovia sakmarae* (Ruzhencev), *Neopronorites tenuis* (Karpinsky), *Medlicottia semota* Ruzhencev, *Metalegoceras noinskyi* Ruzhencev, *M. gerassimovi* Ruzhencev, *Agathiceras uralicum* (Karpinsky), *Crimites subkrotowi* Ruzhencev, *Eoasianites* sp., *Thalassoceras multifidum* Ruzhencev, *Uraloceras limatulum* Ruzhencev, and *Paragastrioceras sintasense* Ruzhencev. Conodonts *Mesogondolella lata* Chernykh, *M. pseudostriata* Chernykh, *Idiognathodus* sp. were also found; the thickness is 10 m.

Bed 38: fine-grained sandstone and siltstone; in the lower part, there is a thin (0.3 m) interlayer of coarse-grained sandstone grading into detrital limestone with fusulinids *Occidentoschwagerina* ? sp., *Pseudofusulina* cf. *irginensis* Schirinkina, *Ps.* cf. *moelleri* (Schellwien), *Ps. decurta* (Korzhenevsky), *Ps. verneuili brevis* Rauser, *Ps.* aff. *vissarionovae ampla* Schirinkina, *Ps.* cf. *declinata* Korzhenevsky, *Ps.* cf. *plicatissima* Rauser, and *Ps. callosa proconcavutas* Rauser; the thickness is 55 m.

Bed 39: coarse-grained polymictic sandstone rich in organic detritus and grading in places into clastic–detrital limestone; the thickness is 1.5 m.

Bed 40: fine-grained loose sandstone; the thickness is 12 m.

Bed 41: thin-platy fine-detrital to pelitomorphic limestone with a thin (0.15 m) interlayer of coarse-detrital limestone that bears smaller foraminifers, red algae, bryozoans, crinoids, bivalves, and spheroidal coral colonies. Abundant fusulinids are represented by *Pseudoendothyra* sp., *Kanmeraia alfa* (Verville, Thompson et Lokke), *Pseudofusulina pedissequa pedissequa* Vissarionova, *Ps. pedissequa adjuncta* Schirinkina, *Ps. buranchini* Rauser, and *Ps.* aff. *urdalensis* Rauser. They coexist with rare ammonoids *Andrianovia sakmarae* (Ruzhencev), *Agathiceras uralicum* (Karpinsky), *Neopronorites* sp. Single specimens of conodonts *Mesogondolella* aff. *lata* Chernykh were also found; the thickness is 2 m.

Bed 42: fine-grained sandstone; the thickness is 12 m.

Bed 43: compact fine-detrital to pelitomorphic limestone with rare ammonoids *Artinskia artiensis* (Grunewaldt), *Neopronorites* aff. *skvorzovi* (Tchernov), *Neoschumardites* sp. (aff. *N. triceps*), and with conodonts *Streptognathodus elongatus* Gunnell, *S. constrictus* Chernykh et Reshetkova, *Hindeodus minu-*

tus (Ellison), *Mesogondolella bisselli* Clark et Behnken, and *M. visibilis* Chernykh; the thickness is 4 m.

The total thickness of the Kondurovka Formation is 310 m.

Aktasty Formation

Bed 43 is traceable northward along the strike for a distance of 1 km to the creek with a dam (Fig. 2), and the section was continued here further along the right slope of the creek. Bed 43 underlies here the following beds.

Bed 44: polymictic sandstone and siltstone with thin mudstone interlayers; the thickness is 140 m.

Bed 45: platy pelitomorphic to fine-detrital limestone; the thickness is 0.5 m.

Bed 46: polymictic medium-grained sandstone; the thickness is 25 m.

Bed 47: compact fine-grained siltstone and sandstone grading into sandy-detrital limestone with rare fusulinids *Pseudoendothyra* sp., *Schubertella* sp., *Rugosofusulina* sp., *Pseudofusulina* ex. gr. *moelleri* (Schellwien), and *Ps. sterlitamakensis* Grozdilova, which coexist with poorly preserved ammonoids, bryozoans, and crinoids; the thickness is 9 m.

Bed 48: loose, poorly exposed sandstone and siltstone; the thickness is 78 m.

Bed 49: compact fine-grained calcareous sandstone with interlayers (up to 0.15 m) of sandy-detrital limestone. Rocks reveal indefinable impressions of ammonoids; the thickness is 3 m.

Bed 50: polymictic medium-grained loose sandstone; the thickness is 70 m.

Bed 51: compact coarse-grained sandstone crossed by an old trench; the thickness is 3 m.

Bed 52: loose, medium- to fine-grained sandstone; the thickness is 18 m.

Bed 53: siltstone alternating with compact platy medium-grained sandstone; a thin (0.15 m) interlayer of pelitomorphic to fine-detrital limestone occurring in the bed yields rare fusulinids *Pseudoendothyra* sp., *Schubertella* sp., and *Pseudofusulina sterlitamakensis* Grozdilova. Well-preserved ammonoids *Neoshumardites triceps* Ruzhencev, *Artinskia artiensis* (Grunewaldt), *Daraelites elegans* Tchernow, *Neopronorites permicus* (Tchernow), *Uraloceras* sp., *Thalassoceras gemmellaroi* Karpinsky, *Popanoceras annae* Ruzhencev, *P. tschernowi* Maximova, and *Paragastrioceras* sp. are found in sandstone and siltstone, which also enclose a large coral colony, fragments of petrified wood, and coalified plant detritus. The bed is crossed by the creek upstream of the dam. It is well traceable along the strike in an old trench, in which the rocks are exposed northward and southward for a distance of several kilometers; the thickness is 10 m.

Bed 54: poorly exposed interval of the section; judging from isolated outcrops and debris, it is mainly composed of polymictic sandstone and siltstone, among which subordinate mudstone may present; the thickness is 130 m.

Bed 55: compact, coarse- to medium-grained polymictic sandstone grading in places into sandy detrital limestone with abundant fusulinids, smaller foraminifers, bryozoans, crinoids and plant detritus. Fusulinid species identified in the bed are *Pseudoendothyra* sp., *Schubertella* sp., *Waeringella* sp., *Rugosofusulina* aff. *angustospiralis* Scherbovich, *R. brevis* Leven et Scherbovich, *Pseudofusulina concavutas* Vissarionova, *Ps. pedissequa adjuncta* Shirinkina, *Ps. sulcata* Korzhenevsky, *Ps. declinata* Korzhenevsky, *Ps. ischimbajevi* Korzhenevsky, *Ps.* cf. *verneuili* (Moeller), *Ps.* aff. *plicatissima* Rauser, *Ps.* aff. *karagasensis ventricosa* Rauser, *Ps. gregaria shustovensis* Scherbovich, *Ps. aequalis* Kireeva, and *Globifusulina firma* (Shamov). The bed descends towards the creek directly behind the dam; the thickness is 10 m.

Bed 56: fine-grained polymictic sandstone and siltstone crumbling into chippings; the thickness is 50 m.

Bed 57: compact fine-grained sandstone and siltstone with interlayers of sandy detrital limestone that yields rare tests of fusulinids, smaller foraminifers, bryozoan remains, and indefinable imprints of ammonoids. Identified fusulinids taxa are *Pseudoendothyra* sp., *Pseudostaffella* sp., *Schubertella* sp., *Depratina* sp., *Pseudofusulina* ex. gr. *gregaria* (Lee), *Ps. seleukensis* Rauser, and *Ps.* ex. gr. *sulcata* Korzhenevsky; the thickness is 8 m.

Bed 58: poorly exposed interval of the section presumably composed of medium- to fine-grained sandstone and less widespread siltstone and mudstone interlayers. Two interlayers of polymictic gravelstone with rare indefinable *Pseudofusulina* forms occur in the upper part of the bed; the thickness is 260 m.

Bed 59: compact calcareous mudstone; the thickness is 10 m.

Bed 60: poorly exposed interval of the section with sandstone and siltstone debris; the thickness is 350 m.

Bed 61: very compact calcareous fine-grained sandstone and siltstone with thin interlayers of coarse-grained polymictic sandstone; the rocks are exposed on the crest of a prominent small ridge with a sole tree; the ridge crosses the creek a few hundreds of meters downstream of the dam. A trench extends along the bed that is 30 m thick.

Bed 62: unexposed interval with isolated small ridges, which are composed, judging from debris, of coarse-grained polymictic sandstone bearing rare indefinable fusulinids; the thickness is 43 m.

Bed 63: poorly exposed interval of the section; isolated small outcrops of clearly laminated medium-grained sandstone with subordinate interlayers and lenses of coarse-grained silicified sandy-detrital lime-

stone are encountered. Plant detritus, fusulinids, and ammonoids are found in one of the outcrops. Fusulinids are poorly preserved, and species established among them are *Pseudofusulina* cf. *juresanensis* Rauser, *Ps.* cf. *postpedissequa* Rauser, *Ps.* aff. *kutkanensis transcedens* Rauser, *Ps.* cf. *pseudoconcavutas* Rauser, *Ps.* aff. *arlarovi* Rauser, and *Ps.* cf. *ovata* Rauser. *Artinskia artiensis* (Grunewaldt) is the only species identified among ammonoids; the thickness is 52 m.

The total thickness of the Aktasty Formation is about 1300 m.

In the next unexposed interval (100 m), individual areas of platy sandstone and siltstone debris were encountered. They are confined to small uplifts in the relief and extend along the general strike of beds. Farther along the section line, we observed placers of pebbles and boulders of different composition and roundness. Pebbles in the placers decrease in size southwards to disappear subsequently. The conglomeratic strip is followed by a series of karst windows with gypsum incrustation on the walls. The affiliation of conglomerates to the section is not obvious, although Pnev and Polozova (1981) reported on their occurrence in the Sarga Horizon that is 549 m thick. It is likely that these researchers studied the section north of the described one, where it is better exposed and represented more completely. It may be as well that conglomerates are pinching out in the southern direction and replaced by sandstone. It is also conceivable that they are truncated by the unconformity surface at the base of the Kungurian deposits, if it is granted that such an unconformity exists.

Section 2 spans the Uskalyk, Kurmaya, Karamurun, and Sarabil' formations. It is located 1 km northward of the section described above, in the right bank of a creek along which the country road runs crossing a chain of limestone outcrops of the Kurmaya and Sarabil' formations directly to the north of the electric power line and a noticeable summit with a retranslation antenna mast (Fig. 2). The description of the section begins again at the anticline core to be continued along the western limb of the structure.

Uskalyk Formation

Bed 1: as the lowermost part of the section in the anticline, core is not exposed, the bed is characterized based on separate spots of sandstone and siltstone debris. In high landforms, sandstones are more coarse-grained, grading into detrital limestone with abundant fusulinids *Pseudoendothyra* sp., *Parastafelloides* sp., *Biwaella* ? sp., *Schubertella* sp., *Fusulinella usvae plicata* Kireeva, *F. pulchra* Rauser, *Sphaeroschwagerina constans* (Scherbovich), *S. sphaerica* (Scherbovich), *S. shamovi* (Scherbovich), *Pseudoschwagerina uddeni* (Beede et Kniker), *P. beedei* Dunbar et Skinner, *Pseudofusulina gregaria* Lee, *Ps. paragregaria paragregaria* Rauser, *Ps. paragregaria ascedens* Rauser, *Ps. nana* Sjomina, *Ps. sulcata* Korzhenevsky, *Ps. ischimbajevi* Korzhenevsky, *Ps. declinata* Korzhenevsky, *Globifusulina firma* (Rauser), and *G. sphaerica* (Beljaev). The thickness of unexposed part of the section is about 100 m.

Bed 2: poorly exposed interval of the section; judging from debris composition and small outcrops, coarse-grained polymictic sandstones grading into sandy detrital limestones represent the basal portion of the bed. These rocks are replaced upward by fine-grained sandstone and then by siltstone and mudstone. Detrital limestone yields rare fusulinids *Schubertella* sp. and *Globifusulina firma* (Shamov); the thickness is 20 m.

Bed 3: a similar rock succession with rare *Schubertella* sp., *Pseudofusulina* sp. found in detrital limestone; the thickness is 20 m.

Bed 4: white to light gray, slightly yellowish, pelitomorphic limestones; the thickness is 4 m.

Bed 5: rhythmically alternating coarse-grained polymictic sandstone (passing into sandy detrital limestone at the base of rhythms), fine-grained sandstone, siltstone, mudstone, and pelitomorphic limestone; detrital limestone levels yield remains of colonial corals, bryozoans, brachiopods, crinoids, and algae. Among abundant fusulinids, there are *Fusiella* ? sp., *Pulchrella* sp., *Schubertella kingi exilis* Suleimanov, *Sch. paramelonica* Suleimanov, *Sch.* aff. *excelsa* Shamov, *Mesoschubertella* ? sp., *Rugosofusulina shikhanensis* Suleimanov, *R. pulchella pulchella* Rauser, *R. pulchella firma* Suleimanov, *R. shaktauensis shaktauensis* Suleimanov, *R. shaktauensis ellipsoides* Suleimanov, *R. kulahoensis* Leven et Scherbovich, *Dutkevitchia* cf. *ruzhencevi* (Rauser), *Sphaeroschwagerina sphaerica* (Scherbovich), *Sph. constans* (Scherbovich), *Globifusulina sphaerica* (Beljaev), *Pseudofusulina paragregaria* Rauser, *Ps. liuchovensis* (Chen), and *Ps. sulcata* Korzhenevsky; the thickness is 50 m.

Kurmaya Formation

Bed 6: light gray, compact, pelitomorphic limestone with an interlayer (1–1.5 m) of massive limestone conglomeratic breccia near the top; the thickness is 100–110 m.

Karamurun Formation

Bed 7: mudstone, siltstone and fine-grained sandstone alternating with light-colored pelitomorphic and fine-detrital limestone dominating in the middle part of the unit. In this part and near the top, there are thin interlayers of coarse-grained polymictic sandstone grading into sandy detrital and fusulinid limestones. Identified fusulinid taxa are *Eostaffella* sp., *Pseudoendothyra* sp., *Schubertella* sp., *Pseudostaffella antiqua* (Dutkevich), *Neostaffella sphaeroidea cuboides* (Rauser), *Pseudoendothyra* sp., *Depratina prisca*

(Deprat), *Pulchrella* sp., *Montiparus* ? sp., *Rugosofusulina intermedia* Suleimanov, *R. serrata valens* Rauser, *Sphaeroschwagerina shamovi* (Scherbovich), *Globifusulina* cf. *electa* (Shamov), *Pseudofusulina moelleri moelleri* (Schellwien), *Ps. moelleri implicata* (Schellwien), *Ps. paraimplicata* Kireeva, *Ps.* cf. *paramoelleri* Rauser, *Ps.* aff. *aequalis* (Schellwien), *Ps. gregaria* Lee, *Ps. lutuginiformis* Rauser, *Ps. pointeli* Rauser, *Ps. sulcata* Korzhenevsky, *Ps. mirabilis* Rauser, *Ps. ischimbajevi* Korzhenevsky, *Ps. composita* Korzhenevsky, *Ps. blochini belatula* Korzhenevsky, *Ps.* cf. *conspiqua* Rauser, *Ps. decurta* Korzhenevsky, *Ps. rauserae* Korzhenevsky, and *Ps. bashkirica acuminata* Kireeva; the thickness is 100–110 m.

Bed 8: medium- to fine-grained sandstone and siltstone with mudstone interlayers; the thickness is 60–70 m.

Sarabil' Formation

Bed 9: light-colored pelitomorphic limestone; the thickness is 130–150 m.

BIOSTRATIGRAPHIC ANALYSIS

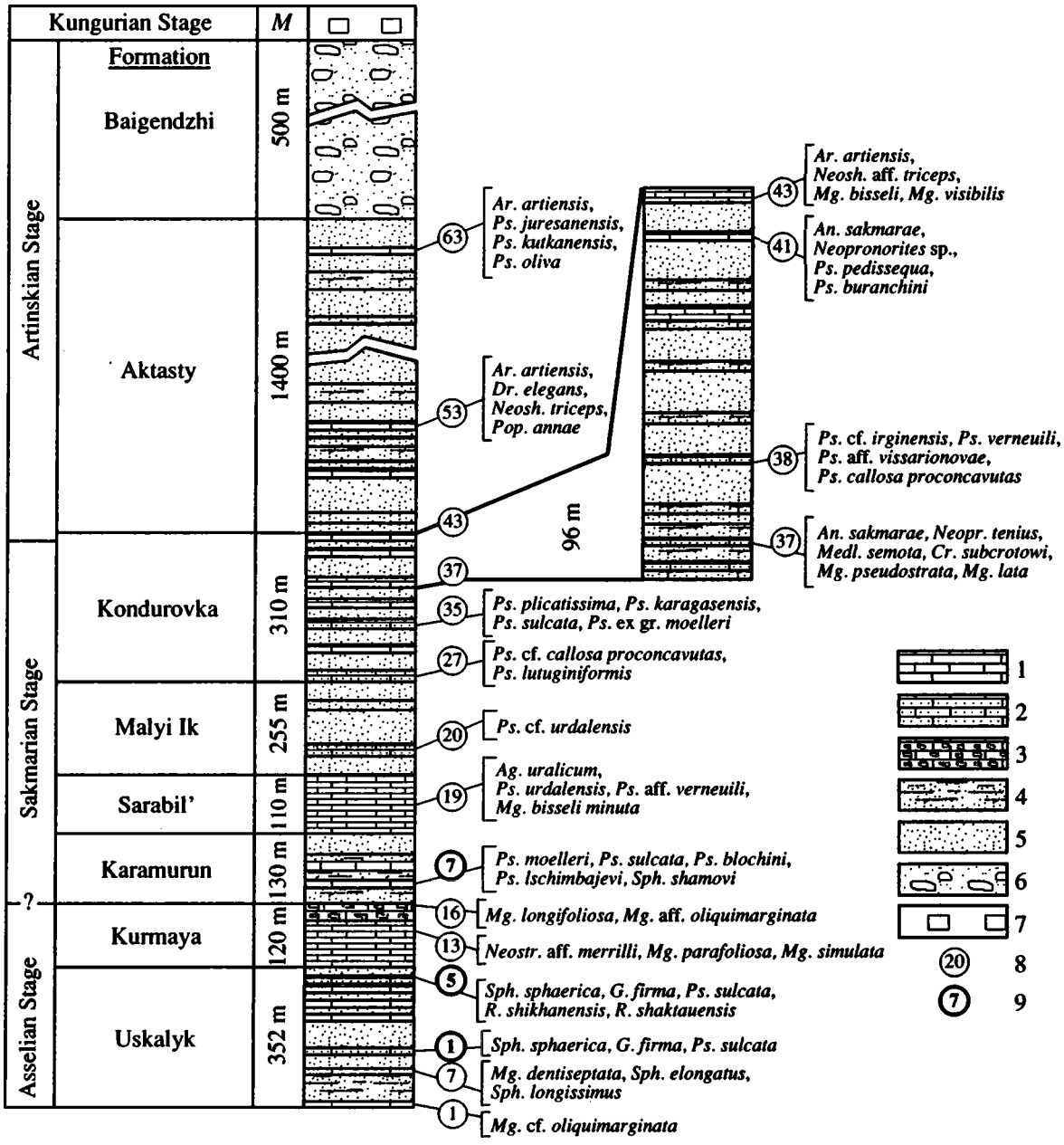
Two sections described above supplement each other and taken together span the stratigraphic interval from the middle Asselian to Artinskian Stage included. All the formations established previously in the Kondurovka section (Ruzhentsev, 1951) are well distinguishable in the composite section (Fig. 3), in which the Artinskian Stage is represented most completely. In paleontological characterization, the composite section yields to the Kondurovka section studied now more thoroughly. In some cases however, the collected paleontological material allows us to refine interpretation of the formation ages, e.g., of the Uskalyk and Kurmaya formations. Moreover, it complements paleontologic data, especially on ammonoids already known from the Kondurovka section, which represent key fossils for solution of the Sakmarian–Artinskian boundary problem. Considered below are fusulinid, ammonoid and conodont assemblages established in the described sections. They represent fossil groups, which are of crucial importance for dating and correlation of the beds.

Fusulinids are best represented in the section, although their distribution is very irregular. Assemblages of these fossils are usually rich in redeposited forms, and this complicates dating of beds hosting them. Nevertheless, being rather abundant, fusulinids are of decisive importance for age determinations. Exactly these fossils were used to determine ages of the Uskalyk and Kurmaya formations, as it is evident from works by Ruzhentsev (1950, 1951), Rauser-Chernousova (1965), Pnev (1978), and Polozova (1978, 1979).

The oldest of the described fusulinids have been collected 200 m below the top of the Uskalyk Formation (Bed 1, Section 2; see Fig. 3). According to formation thickness calculated by Ruzhentsev (400–420 m), this level corresponds to its middle part. Along with species typical of the middle zone of the Asselian Stage, such as *Pseudoschwagerina beedei, P. uddeni*, and *Sphaeroschwagerina shamovi*, we encountered here abundant *Sphaeroschwagerina constans* and *S. sphaerica* forms, which appear in the middle zone, but are dominants in the upper zone of the Asselian Stage. *Globifusulina firma*, the index species of the upper zone of the Asselian Stage, and forms of the *Pseudofusulina sulcata* group, the prosperity time of which corresponds to the Tastuba Horizon of the Sakmarian Stage, also appear at the level under consideration.

The fusulinid assemblage from an upper part of the Uskalyk Formation (Bed 5, Section 2) is similar to the previous one, though its distinctive feature is presence of abundant *Rugosofusulina* forms. Among the latter, there are dominant species described by Suleimanov (1949) from the upper part of the Asselian and the lower part of the Sakmarian stages of the Urals (Bashkortostan). These data indicate that, contrary to Rauser-Chernousova's opinion (1965), at least the upper half of the Uskalyk Formation should be referred to the upper *Sphaeroschwagerina sphaerica–Globifusulina firma* Zone of the Asselian Stage. This inference completely coincides with data reported by Polozova (1978, 1979) on northerly sections exposed along the Syuren' and Assel' rivers. As is shown below, it is important in the light of problems related to the boundary position between the Asselian and Sakmarian stages.

In the Kurmaya Formation, we found fusulinids only in conglomeratic breccia crowning the formation section. These are *Pseudoendothyra* sp., *Eostaffella* sp., *Ozawainella* sp., *Pseudostaffella antiqua, Schubertella* aff. *kingi exilis, Sch. paramelonica, Pseudofusulinella* sp., *Triticites parvulus, Rugosofusulina* sp., and *Pseudofusulina paragregaria ascedens*. Most of the listed forms are redeposited, except for the last one typical of the upper zone of the Asselian Stage. According to data obtained by Ruzhentsev (1951), Rauser-Chernousova (1965), Polozova (1979), Chuvashov *et al.* (1991) in northerly section, the fusulinid assemblage from this formation is not diverse, trivial, and similar in general to the assemblage from the underlying Uskalyk Formation. However, Rozovskaya who identified fusulinids collected by Ruzhentsev from the section along Uskalyk River reported that the lower part of the Kurmaya Formation bears single specimens of *Pseudofusulina moelleri*, the index species of the lower zone of the Sakmarian Stage (Ruzhentsev, 1951). Polozova found the same species later on that allowed her to refer the Kurmaya Formation to the Sakmarian Stage. Several forms of the *P. moelleri* group were also found by Davydov in the upper third of the formation (Davydov and Leven, 1999). All these data cast doubts upon conclusion of Ruzhentsev and Rauser-Chernousova who attributed the entire Kurmaya Formation to the Asselian Stage.


Kungurian Stage
M
Formation
Baigendzhi
500 m
Artinskian Stage
Aktasty
1400 m
Kondurovka
310 m
Sakmarian Stage
Malyi Ik
255 m
Sarabil'
110 m
Karamurun
130 m
?
Kurmaya
120 m
Asselian Stage
Uskalyk
352 m
96 m
63 Ar. artiensis, Ps. juresanensis, Ps. kutkanensis, Ps. oliva
53 Ar. artiensis, Dr. elegans, Neosh. triceps, Pop. annae
43 Ar. artiensis, Neosh. aff. triceps, Mg. bisseli, Mg. visibilis
41 An. sakmarae, Neopronorites sp., Ps. pedissequa, Ps. buranchini
38 Ps. cf. irginensis, Ps. verneuili, Ps. aff. vissarionovae, Ps. callosa proconcavutas
37 An. sakmarae, Neopr. tenius, Medl. semota, Cr. subcrotowi, Mg. pseudostrata, Mg. lata
35 Ps. plicatissima, Ps. karagasensis, Ps. sulcata, Ps. ex gr. moelleri
27 Ps. cf. callosa proconcavutas, Ps. lutuginiformis
20 Ps. cf. urdalensis
19 Ag. uralicum, Ps. urdalensis, Ps. aff. verneuili, Mg. bisseli minuta
7 Ps. moelleri, Ps. sulcata, Ps. blochini, Ps. Ischimbajevi, Sph. shamovi
16 Mg. longifoliosa, Mg. aff. oliquimarginata
13 Neostr. aff. merrilli, Mg. parafoliosa, Mg. simulata
5 Sph. sphaerica, G. firma, Ps. sulcata, R. shikhanensis, R. shaktauensis
1 Sph. sphaerica, G. firma, Ps. sulcata
7 Mg. dentiseptata, Sph. elongatus, Sph. longissimus
1 Mg. cf. oliquimarginata
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20 8
7 9

Fig. 3. Composite section of Lower Permian deposits near the Verkhneozernoe Village: (1) pelitomorphic and organogenic detrital limestones; (2) sandy limestone; (3) conglomeratic limestone breccia; (4) siltstone or mudstone; (5) sandstone; (6) conglomerate; (7) gypsum; (8) number of unit bearing fauna in Section 1; (9) ditto in Section 2; (*G*) *Globifusulina*; (*Ps.*) *Pseudofusulina*; (*R.*) *Rugosofusulina*; (*Sph.*) *Sphaeroschwagerina*, (*Ag.*) *Agathiceras*; (*An.*) *Andrianovia*; (*Ar.*) *Artinskia*; (*Neopr.*) *Neopronorites*; (*Neosh.*) *Neoshumardites*; (*Dr.*) *Daraelites*; (*Medl.*) *Medlicottia*; (*Pop.*) *Popanoceras*; (*Mg.*) *Mesogondalella*; (*Str.*) *Streptognathodus*; (*Neostr.*) *Neostreptognathodus*. (M) thickness.

The fusulinid assemblage from the Karamurun Formation (Section 2, Bed 7) undeniably belongs to the Sakmarian Stage (Tastuba Horizon). This is evident from abundance of *Pseudofusulina moelleri* zonal species, which associates with *Paraschwagerina juresanensis, Pseudofusulina aequalis, Ps. paraimplicata, Ps. sulcata, Ps. mirabilis, Ps. ischimbajevi, Ps. composita, Ps. blochini belatula, Ps. rauserae*, and *Ps. bashkirica acuminata*, all typical of the Tastuba Horizon. It is remarkable that these Sakmarian species coexist with abundant *Sphaeroschwagerina* forms. Up to date, this genus was thought to be disappearing at the boundary between the Asselian and Sakmarian stages, and this event used to be considered as indicative of that boundary in the sections, while rare findings of its representatives in Sakmarian deposits were accounted for redepo-

sition (Rauser-Chernousova, 1965). In our samples from the Karamurun Formation, *Sphaeroschwagerina* forms are rather frequent, well preserved, and lacking signs of redeposition. Taking into consideration that this genus is equally characteristic of the Sakmarian and Asselian stages in the Tethyan realm (Leven and Shcherbovich, 1980), and that in China it coexists even with Artinskian ammonoids (Zhou Zu-ren, 1988), findings of *Sphaeroschwagerina* forms in Sakmarian deposits of the Urals should be regarded as quite natural.

The Sarabil' Formation used to be assigned to the upper part of the Tastuba Horizon (the *Pseudofusulina verneuili* Zone). Few fusulinids in our samples from the mentioned formation (Section 1, Bed 19) are consistent with this assignment. In addition to the zonal species, their assemblage includes forms of the *Ps. urdalensis* group. The peak abundance of the latter is recorded in the Sterlitamak Horizon (the *Pseudofusulina urdalensis* Zone), but some of representatives of the group, such as *Ps. urdalensis abreviata*, are known even from the upper part of the Tastuba Horizon in Bashkortostan, the Cis-Urals region (Rauser-Chernousova, 1949a).

The Malyi Ik Formation is poorly characterized by fauna in our collection. *Pseudofusulina urdalensis* present in this subdivision (Section 1, Bed 20) indicates its affiliation with the Sterlitamak Horizon of the Sakmarian Stage, thus confirming the early conclusions by Ruzhentsev (1951) and Rauser-Chernousova (1965). The greater part of the Kondurovka Formation also belongs to the Sterlitamak Horizon, as it is evident from presence of *Pseudofusulina plicatissima, Ps. karagasensis*, and *Ps.* cf. *callosa proconcavutas* in this interval (Section 1, beds 27 and 35). At the base of Bed 38, there appear forms, which are poorly preserved but resemble Artinskian *Pseudofusulina irginensis* and *Ps. vissarionovae ampla*. This unit likely corresponds to Bed 6 of the section described by Pnev and Polozova (1981) who regarded this bed as basal one in the Artinskian Stage. Bed 41 yielded abundant *Pseudofusulina pedissequa* (*sensu* Schirinkina). In opinion of Shirinkina (1980), this species is typical of the base of the Artinskian Burtsevo Horizon, while Chuvashov *et al.* (1990) reported on its occurrence in upper Sakmarian beds and in layers transitional to the Artinskian Stage (the Siryat' section).

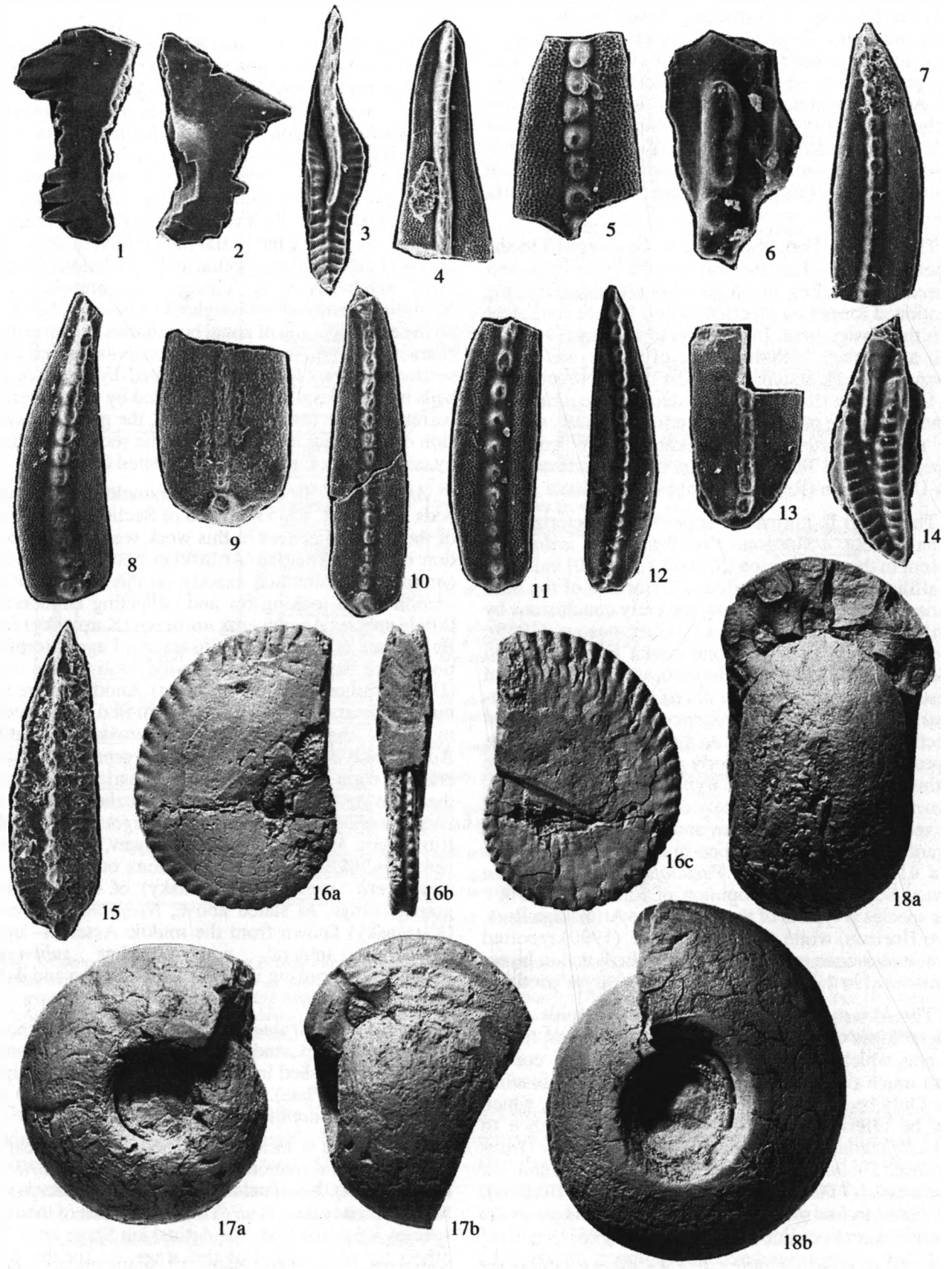
The Aktasty Formation is poor in fusulinids. Their assemblages consist exclusively of redeposited forms, among which Sakmarian taxa dominate and coexist with much older, even Middle Carboniferous fusulinids. Only beds 57 and 63 yielded several forms, which can be referred with some degree of confidence to *Pseudofusulina seleukensis, Ps. kutkanensis transcedens, Ps. monstrata, Ps. postpedissequa*, and *Ps. juresanensis* of the Artinskian Stage (the Irga Horizon). We failed to find younger fusulinid assemblages in the described section. Pnev and Polozova (1981) reported that they were encountered in the upper, mostly conglomeratic part of the section, which is lacking however the characteristic species of biostratigraphic importance.

Our analysis implies that all fusulinid zones, beginning from the upper *Sphaeroschwagerina sphaerica–Pseudofusulina firma* Zone of the Asselian Stage and ending with the *Pseudofusulina juresanensis–Parafusulina lutugini* Zone of the Artinskian Stage, are recognizable in the described section. In any case, however, it is impossible to establish exact boundaries of zones and, hence, boundaries of the stages. Moreover, there is no way to do it at all, since the attention was focused always, by the initial recognition of zones and during subsequent description and correlation of recognized subdivisions, on changes in composition of fusulinid assemblages throughout the section, but never on the exact position of zonal boundaries and on criteria characterizing them. As far as it concerns the described section, the problem is complicated by the fact that beds bearing fusulinids are separated by large intervals barren of these fossils. In addition, the general succession of changing assemblages in the section is blurred by occurrence of abundant redeposited forms.

Ammonoids. Remains of ammonoids are found in beds 19, 37, 41, 43, 53, and 63 of Section 1. Since one of the main objectives in this work was to refine position of the Sakmarian–Artinskian boundary, we concentrated our attention exactly on this interval of the section when looking for and collecting ammonoids. Single species *Agathiceras uralicum* (Karpinsky) from Bed 19 are of little interest in terms of age determination, since they are of a very wide stratigraphic range (Upper Carboniferous–Artinskian). Another, more representative assemblage was found in Bed 37 located 86 m below the top of the Kondurovka Formation. Ammonoids collected from this unit represent six genera and eight species. Typical Sakmarian forms amid them are *Andrianovia sakmarae* (Ruzhencev), *Medlicottia semota* Ruzhencev, *Metalegoceras noinskyi* Ruzhencev, *M. gerassimovi* Ruzhencev, and *Thalassoceras multifidum* Ruzhencev. Among others, there are *Agathiceras uralicum* (Karpinsky) of a wide stratigraphic range, as stated above, *Neopronorites tenuis* (Karpinsky) known from the middle Asselian– upper Sakmarian interval, and *Crimites subkrotowi* Ruzhencev occurring in both the Sakmarian and Artinskian stages.

Species *Andrianovia sakmarae* (Ruzhencev), *Neopronorites* sp., and *Agathiceras uralicum* (Karpinsky) are established in Bed 41, i.e., about 70 m higher in the section (Plate). The first one is of Sakmarian age, and two others are of wider stratigraphic ranges.

Bed 43 that is located 16 m above Bed 41 near the Kondurovka Formation top yielded *Artinskia artiensis* (Grunewaldt), *Neoshumardites* sp., (aff. *N. triceps*) and *Neopronorites skvorzowi* (Tchernov). First of the listed species is known from the Artinskian Stage only. Two others are also typical of this stage. As for the genus *Neoshumardites*, it should be noted that it is in phyletic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relations with the genus *Andrianovia*, and its representative from Bed 43 shows morphological features suggesting its intermediate position between the Sakmarian *Andrianovia sakmarae* and Artinskian *Neoshumardites triceps*. We did this conclusion based on peculiarities of the inner fragment of the lobe line, in which the dorsal and inner lateral lobes are rather narrow (much narrower than in *Andrianovia* forms, but wider than in *Neoshumardites* species), elongated, with moderately developed processes on lateral sides that is typical of the genus *Neoshumardites*. Moreover, the preserved shell fragments exhibit the reticulate sculpturing with well-developed longitudinal and transverse elements. In the *Andrianovia–Neoshumardites* phylogenetic lineage, the distinct prevalence of unidirectional elements, longitudinal in the former genus and transverse in the latter one, was noted (Ruzhentsev, 1952, 1956; Andrianov, 1985; Nassichuk *et al.*, 1965; Boardman *et al.*, 1994). Hence, the species from Bed 43 can be regarded as a predecessor of a younger species *N. triceps*. In this work, we classified the found species in the open nomenclature, since it cannot be properly described because of a poorly preserved shell remains.

Eight genera and seven species of ammonoids are established in Bed 53 of the Aktasty Formation, i.e., 250 m higher in the section. They all do not occur below the Artinskian Stage. Most of them are distributed throughout the stage range, and only *Popanoceras tschernowi* Maximova is confined exclusively to the Aktasty Horizon.

The uppermost unit that yielded ammonoids is Bed 63 crowning the Aktasty Formation. These were only species *Artinskia artiensis* (Grunewaldt) very typical of the Artinskian Stage in the Urals.

Conodonts. Scarce conodonts from the section under consideration have been originally described by Movshovich *et al.* (1979). In the Kondurovka section located northward, these fossils are studied more comprehensively (Chernykh and Reshetkova, 1987a, b; Chuvashov *et al.*, 1990; Chernykh, 1999), and stratigraphic succession of their assemblages is of a reference significance.

In the described section, we found conodonts only in a limited number of samples, mainly in its lower Asselian–Sakmarian part. The distinguished conodont assemblages are not diverse and often rich in redeposited forms, the oldest among which are of the Middle Carboniferous (Bashkirian) age.

Conodonts of the Uskalyk Formation are found in beds 1 and 7 of Section 1 (Fig. 3). They represent species *Streptognathodus elongatus* Gunnell, *S. simplex* Gunnell, *S. longissimus* Chernykh et Reshetkova, *Mesogondolella dentiseptata* Chernykh, and *M.* cf. *obliquimarginata* Chernykh. Except for the last of the listed forms known from the lowermost Sakmarian, all others are characteristic of the middle and upper zones of the Asselian Stage.

In the Kurmaya Formation, conodonts are found at two levels: a bit below the first breccia bed distinguished by Ruzhentsev (about 40 m below the formation top) and very close to the formation roof (the second breccia bed). Their assemblage is rich in forms redeposited from the Bashkirian and Gzhelian stages of the Carboniferous (see the section description for the complete list). It is likely that non-redeposited forms of the assemblage are *Mesogondolella parafoliosa, M. longifoliosa, M. simulata, M. obliquimarginata*, and *Neostreptognathodus* aff. *merrilli*. The first and last taxa are unknown below the base of the Sakmarian Stage. Others also occur within the interval of Sakmarian Stage, although they are of wider stratigraphic ranges.

One more conodont assemblage is found in the upper part of the Sarabil' Formation. It includes only two species: *Mesogondolella bisselli* Clark et Behnken and *M. striata* Chernykh. The former is represented by the *minuta* subspecies described by Chernykh (1999) from the Sarabil' Formation of the Kondurovka section, where the formation is confidently attributed to the lower Sakmarian (upper beds of the Tastuba Horizon). The second transit taxon is also known from Sakmarian deposits, though it is more typical of the Asselian Stage.

Some conodont and ammonoid species of stratigraphic importance from the vicinity of the Verkhneozernoe Village:

(1) *Anchignathodus* sp.; specimen no. 285/15, sample 43/3 (×90), the Kondurovka Formation; (2) *Anchignathodus minutus* (Ellison); specimen no. 285/14, sample 43/1 (×50), the Kondurovka Formation; (3) *Streptognathodus constrictus* Chernykh et Reshetkova; specimen no. 285/13, sample 43/1 (×75), the Kondurovka Formation; (4) *Mesogondolella* cf. *obliquimarginata* Chernykh; specimen no. 285/1, sample 1/1 (×50), the Uskalyk Formation; (5) *Mesogondolella striata* Chernykh; specimen no. 285/2, sample 19/1 (×90), the Sarabil' Formation; (6) *Neostreptognathodus* aff. *merrilli* (Kozur); specimen no. 285/3, sample 13/5 (×150), the Kurmaya Formation; (7) *Mesogondolella visibilis* Chernykh; specimen no. 285/12, sample 43/1 (×35), the Kondurovka Formation; (8) *Mesogondolella parafoliosa* Chernykh; specimen no. 285/11, sample 16/1 (×50), the Kurmaya Formation; (9) *Mesogondolella lata* Chernykh; specimen no. 285/10, sample 37/1 (×60), the Kondurovka Formation; (10) *Mesogondolella longifoliosa* Chernykh; specimen no. 285/5, sample 16/1 (×60), the Kurmaya Formation; (11, 12) (11) *Mesogondolella bisselli* (Clark et Behnken); specimen no. 285/4, sample 43/1 (×75), the Kondurovka Formation; (12) specimen no. 285/6, sample 43/1 (×40), the Kondurovka Formation; (13) *Mesogondolella pseudostriata* Chernykh; specimen no. 285/9, sample 37/1 (×60), the Kondurovka Formation; (14) *Streptognathodus simplex* Gunnell; specimen no. 285/7, sample 7/1 (×80), the Uskalyk Formation; (15) *Gondolella elengatula* Stauffer et Plummer; specimen no. 285/*, sample 13/5 (×50), the Kurmaya Formation; (16a,b,c) *Artinskia artiensis* (Grunewaldt); specimen no. BO11, sample 53 (×15); (17a, b) *Andrianovia sakmarae* (Ruzhencev); specimen no. BO8, sample 41 (×1); (18a, b) *Metalegoceras gerassimovi* Ruzhencev; specimen no. BO10, sample 41 (×1).

We failed to find conodonts in the Malyi Ik Formation, but encountered them in the uppermost beds of the Kondurovka Formation. *Mesogondolella pseudostriata* Chernykh and *M. lata* Chernykh from beds 37 and 41 are typical of the upper half of the Sakmarian Stage. In addition to redeposited *Streptognathodus* and *Hindeodus* forms, Bed 43 crowning the formation yielded *Mesogondolella bisselli* Clark et Behnken and *M. visibilis* Chernykh. These species are characteristic of the upper zone of the Sakmarian Stage, but their findings are known from Artinskian deposits of the Urals as well.

Conodonts have not been found in higher parts of the section.

SAKMARIAN STAGE BOUNDARIES

Ruzhentsev who distinguished the Sakmarian Stage and identified representative assemblages of ammonoids characterizing the stage and the Tastuba and Sterlitamak horizons constituting it left aside, however, the problem of the stage lower boundary. In the Kondurovka section, he placed this boundary between the Kurmaya and Karamurun formations thus imparting it the lithostratigraphic rather than biostratigraphic character. Defining that boundary, Ruzhentsev likely paid main attention to fusulinids rather than to ammonoids. The boundary position between the Kurmaya and Karamurun formations actually cannot be substantiated by distribution of ammonoids, because these fossils have not been found in both formations. At the same time, Rozovskaya (1952) who studied fusulinids from the Kondurovka and neighboring sections reliably correlated the Kurmaya Formation with the upper part of the *Schwagerina* Horizon, and the Karamurun Formation with the Tastuba Horizon of Bashkortostan. Her conclusions were later confirmed by Rauser-Chernousova (1965), and the Asselian–Sakmarian boundary was fixed between the *Schwagerina* Horizon, the range of which was thought to represent the Asselian Stage, and the *Pseudofusulina moelleri* Zone of the Tastuba Horizon.

Ruzhentsev more definitely designated the upper boundary of the Sakmarian Stage correlating it with the Kondurovka Formation roof, where typical Sakmarian *Neopronorites tenius, Medlicottia vetusta*, and *"Preshumardites" sakmarae* were found. Directly above this level, there were found fusulinids *Pseudofusulina concavutas, Ps. vissarionovae*, and *Ps. paraconcessa* typical of the Burtsevo Horizon of the Artinskian Stage in Bashkortostan, the Cis-Urals. Artinskian taxon *Artinskia artiensis* was encountered 90 m above the Kondurovka Formation roof (Ruzhentsev, 1951, p. 20). Taking into account the great total thickness (over 1000 m) of Sakmarian and Artinskian stages, we may state that the boundary between them was set rather exactly. At the same time, Ruzhentsev did not mention a specific section where it can be recognized, and sections he described are lacking characterization of the Artinskian Stage.

Because ammonoids are rare, mostly fusulinids were used in geological practice for distinguishing and correlation of the Sakmarian Stage. The stage boundaries identified on this basis have not been doubted so far, despite some attempts to revise them. However, current requirements to distinguishing stage boundaries are more stringent, and call for choosing limitotypes or Global Stratotype Sections and Points characterizing each demonstrates that neither lower nor upper boundaries of the Sakmarian Stage comply with the requirements. Fusulinids are inappropriate for that purpose because of their provincialism restricting possibility of interregional correlation. Ammonoids are more promising in this respect, but their correlation potential is limited by rare occurrence of these organic remains. In recent years, a considerable attention has been given to conodonts, intense investigation of which is now in progress. It is likely that these fossils can elucidate the precise position of the Sakmarian Stage boundaries, but nobody has succeeded in this direction for the moment. Moreover, it is still unknown how coincident are boundaries depicted based on different fauna groups, in particular, on fusulinids, ammonoids, and conodonts.

The present state of distinguishing the exact position of the Sakmarian Stage boundaries is discussed below.

The lower boundary of Sakmarian Stage, if we place it at the Kurmaya Formation roof, cannot be precisely defined, as mentioned above, based on distribution of ammonoids or fusulinids. The same can be stated with respect to the alternative boundary position at the base of the Kurmaya Formation, as suggested by Polozova (1979). Her data (the appearance of Sakmarian *Pseudofusulina moelleri* and *P. verneuili* at this level) deserve, however, a special consideration, because the upper part of the Uskalyk Formation likely belongs to the upper rather than to the middle zone of the Asselian Stage. Since fusulinids marking the boundary we seek for are endemics unknown beyond the Urals, the selected level should be substantiated based on cosmopolitan faunal groups, e.g., on ammonoids and conodonts, which are almost unknown here.

There is a version to place the lower boundary of the Sakmarian Stage inside the Kurmaya Formation range, as it is proposed in paper by Movshovich *et al.* (1979). In the Verkhneozernoe section, these researchers identified Sakmarian *Mesogondolella bisselli* in the upper third of the formation and distinguished a new species *M. praebisselli* accepted for a predecessor of *M. bisselli*. Chernykh who revised these findings showed that the above identifications are invalid and thus deprived the version of any basis. Wardlaw *et al.* (1999) recently have touched upon this version again. They reported on a transition from *Streptognathodus fusus* to *S. barskovi* (sensu stricto) supposedly established in the lower part of Bed 9 of the Kondurovka section (between the first

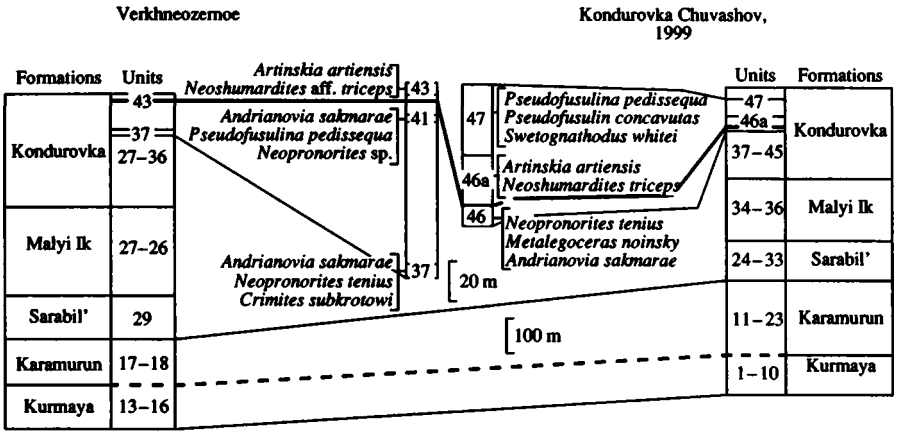

Fig. 4. Correlation of the Sakmarian part of the Verkhneozernoe and Kondurovka sections. A heavy line denotes boundaries of the Sakmarian Stage—proposed (solid line) and arbitrarily assumed (dotted line).

and second breccias). In addition, they collected once more fusulinids of the *Pseudofusulina moelleri* group in the middle part of the formation. These data have been discussed at the colloquium before the 14th International Congress on the Carboniferous and Permian that was held in Calgary (August, 1999). As a result, it has been concluded that conodonts defined as *S. barskovi* represent a new species, and hence their appearance cannot be indicative of the boundary event. At the same time, identifications of fusulinid taxa were approved. Thus, the question of setting up the lower boundary of the Sakmarian Stage within the Kurmaya Formation is open so far.

In the report submitted to the congress in Calgary (Chuvashov, 1999), Chuvashov and Chernykh presented new arguments in favor of placing the boundary under discussion at the roof of the Kurmaya Formation. They correlated it with the first occurrence level of conodonts representing genus *"Sweetognathus"* (=*Neostreptognathodus*). Species *"Sw." merrilli* and ancestral form *Diplognathodus stevensi* were found in this case at the base of the Karamurun Formation, but there is still a possibility that they can be found lower in the section after additional systematic sampling. This chance is not impossible, because we found forms from the Kurmaya Formation, which are similar to *N. merrilli*.

The upper boundary of the Sakmarian Stage has been set up by Ruzhentsev (1951, 1956) theoretically, based on changes in ammonoid assemblages. In fact, he discussed in his works not the boundary of stratigraphic units corresponding to "stages," but an event in evolution of ammonoids, to which the boundary could be confined. It was unclear therewith how long the event was, and hence, how distinct the boundary could be. Changes in ammonoid assemblages declared by Ruzhentsev have not been illustrated in any of sections described by him.

At the time of works by Ruzhentsev devoted to the problem of boundary positioning between the Sakmarian and Artinskian stages, there were attempts to establish this boundary based on distribution of fusulinids. First, Rauser-Chernousova (1940, 1949b) placed it at the base of the Sterlitamak Horizon, though Ruzhentsev (1951) objected her conclusions. Later on, the boundary was displaced at the base of the Burtsevo Horizon, where fusulinids of *Pseudofusulina pedissequa* and *Ps. concavutas* groups appear. According to data available, it is unclear, however, to what extent this event chronologically corresponds to the moment of transition from Sakmarian to Artinskian ammonoid assemblages.

In recent years, conodonts have been regarded as a group of fossils most important for the Permian System subdivision into stages. Nevertheless, the Sakmarian–Artinskian boundary has not yet been identified based on of these fossils. It used to be considered as corresponding to the appearance level of *Sweetognathus whitei*, but first representatives of this conodont species occur already in the uppermost Sakmarian (Kozur, 1998). In general, Kozur concluded that distinctions between conodont assemblages from the Sakmarian Sterlitamak Horizon and Artinskian Aktasty Horizon are insignificant, turning into obvious only if these fossils from the Tastuba and Sterlitamak, or from the Aktasty and Baigendzhi horizons are under comparison.

All the aforesaid suggest that the upper boundary of the Sakmarian Stage, as well as the lower one, are virtual at present rather than real. Only the turning points in evolution of ammonoids and fusulinids, which may be related to this boundary, are more or less clear. Moreover, it is impossible to state now that inferable events in both phyletic lineages were chronologically concurrent. In this case, when we deal with so different groups of organisms, it would be an exception rather than a rule. As for the boundary under consideration, we suggest to define it based on distribution of

ammonoids, which are tolerant and cosmopolitan in contrast to fusulinids. Conodonts are comparable with ammonoids in this respect, but their assemblages cross the Sakmarian–Artinskian boundary without substantial changes, as is mentioned above.

At present, Chuvashov and his colleagues suggest that the Sakmarian–Artinskian limitotype or GSSP should be established in the Kondurovka section (Fig. 4) between Bed 46 (9.1 m thick), which yields Sakmarian *Neopronorites tenuis, Metalegoceras noinskyi*, and *Andrianovia sakmarae*, and Bed 46a (24.5 m thick) with typical Artinskian *Artinskia artiensis, Eothinites* sp., *Neopronorites skvorzovi*, and *Neoshumardites triceps* (Chuvashov, 1999). The fusulinid assemblage from Bed 46 consists of mixed Sakmarian and Artinskian forms. In addition to Sakmarian *Pseudofusulina urdalensis*, it includes Artinskian species *P. adelpha, P. prima*, and *P. irginaeformis*. We did not find fusulinids in Bed 46a, but typical Artinskian *Pseudofusulina pedissequa, P. concavutas*, and *P. buranchini* occur in Bed 47 that is 35 m thick. Conodonts *Sweetognathus whitei* were also found here.

In the studied Section 1, the boundary in question can be placed as precisely as in the Kondurovka section (Figs. 3, 4). The representative ammonoid assemblage from Bed 37 (10 m thick) is typical Sakmarian. In Bed 41 (2m thick), ammonoids are rare, *Andrianovia sakmarae* present among them indicates the Sakmarian age of the unit. Twelve meters upward in the section, Bed 43 (4 m thick) yields *Artinskia artiensis* and *Neopronorites skvorzovi* typical of the Artinskian Stage in association with forms whose morphology is transitional between the Sakmarian *Andrianovia sakmarae* found below and the Artinskian *Neoshumardites triceps*. Hence, the boundary between the Sakmarian and Artinskian stages can be placed inside Bed 42 that is 12 m thick. Fusulinids from Bed 41 are incompatible with this inference. They are represented by Artinskian taxa *Pseudofusulina pedissequa pedissequa, P. pedissequa adjuncta*, and *P. buranchini* typical of the Burtsevo Horizon base. Artinskian forms were also found in the Kondurovka section a bit below the boundary established on the basis of ammonoids. Thus, changes in ammonoid assemblages appear to be lagged behind those in fusulinid assemblages. This time lag seems, if it is remembered that the section interval, in which ammonoid and fusulinid assemblages were completely renewed, was not long as compared to that corresponding to the total thickness of the Sakmarian–Artinskian deposits.

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Ammonoid Zones of the Olenekian Stage (Lower Triassic) and Their Correlation

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Abstract—Regional ammonoid zonations in Olenekian marine deposits of Siberia, Canada, the United States, Primor'e, China, Nepal, the Salt Range, and Mangyshlak Peninsula are considered. The Siberian zonal scheme is the most complete and detailed, consisting of seven zones and twelve subzones, which exemplify a continuous succession of ammonoid assemblages. Beyond a doubt, this scheme can be used as a global chronostratigraphic standard of the Olenekian Stage. Analogues of Siberian ammonoid zones are easily distinguishable everywhere within the lower Olenekian interval. The interregional correlation of upper Olenekian subdivisions is less convincing because of significant geographic differentiation of ammonoids at that time.

Key words: Lower Triassic, Olenekian Stage, biozonation, ammonoid assemblages, interregional correlation.

Kiparisova and Popov (1956) who distinguished the Olenekian Stage regarded as its stratotype an exposure in the Olenek River lower courses. They defined, however, the stratotype area of the stage rather than the particular type section. In a subsequent attempt to correct the situation, Lazurkin and Korchinskaya (1963) suggested to choose for the stage stratotype another section exposed at the Olenek River bank near the Mengilyakh Creek mouth, where the diverse assemblages of late Scythian ammonoids were already found in the 19th century.

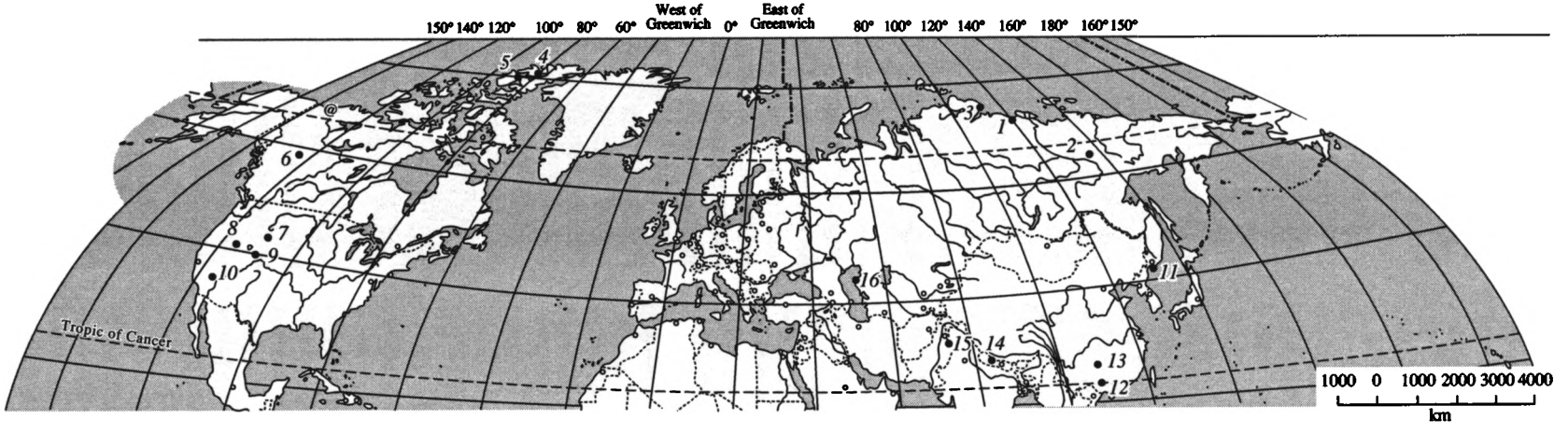
Further investigations of Triassic deposits in Siberia showed that the stratotype area selected for the Olenekian Stage is inappropriate. First, it is impossible to detect here the ammonoid succession in the transitional Induan–Olenekian strata, because the Induan Stage is represented within the area by lagoonal and continental facies. Second, the local record of Olenekian ammonoids is incomplete, and their succession is lacking many zonal taxa known from other Olenekian sections of Siberia.

Another problem of selecting the GSSP for the Induan–Olenekian boundary appeared recently and immediately triggered a keen polemics. Zakharov (1994) suggested that the best candidate for the GSSP is a section exposed in a canyon near the Tri Kamnya Cape, the western coast of the Ussuriiskii Bay. Dagys (1997) was decisively against his suggestion and regarded as most appropriate the sections in the eastern Verkhoyansk region, primarily in the Tompo River basin, where a continuous succession of ammonoid zones across that boundary has been established. The classical section of the Salt Range in Pakistan cannot also be discarded as an appropriate candidate for the GSSP, and the Working Group of Subcommission on Triassic Stratigraphy that was created to solve the problem has to make a difficult decision. My own preference is version suggested by Dagys, because I think that the lower Olenekian boundary stratotype should be sought for in Siberia, where the stage has been originally distinguished, and where particular sections are obviously promising.

REGIONAL ZONAL SCHEMES OF THE OLENEKIAN STAGE

Stratigraphic scheme elaborated for Olenekian deposits of *Siberia* is very detailed and most complete among others. It is based on successive ammonoid assemblages studied in sections of the eastern Verkhoyansk region, Olenek River lower courses, and eastern Taimyr Peninsula (Dagys and Ermakova, 1988, 1990, 1993; Dagys, 1994, 1995, 1999; Ermakova, 1999, see figure).

In the lower Olenekian part, the scheme includes the *Hedenstroemia hedenstroemi, Lepiskites kolymensis,* and *Anawasatchites tardus* zones. Stratotypes of the former two units are located at the Lerkeer River banks (the Tompo River basin), and hypostratotype of the *tardus* Zone is selected in the Kulu River basin (area of the Kolyma River headstream). Dominant species of the *hedenstroemi* Zone are *Hedenstroemia hedenstroemi* (Keyserling) and *H. tscherskii* (Popow). The *kolymensis* Zone yields diverse species of *Lepiskites, Kelteroceras, Clypeoceratoides, Meekoceras, Arctoceras, Euflemingites, Juvenites,* and *Melagathiceras* genera, which are characteristic of this level only. These taxa coexist with *Sakhaites, Anakashmirites,* and *Pseudoceltites* forms, and with last representatives of the genus *Hedenstroemia. Xenoceltites, Anawasatch-*



Geographic localities of Olenekian key sections: (1) Olenek River lower courses, the stratotype area of the stage; (2) eastern Verkhoyansk region; (3) eastern Taimyr, the parastratotype area of the upper Olenekian; (4) Ellesmere Island, the stratotype area of the Smithian and Spathian stages; (5) Axel Heiberg Island; (6) northeastern British Columbia; (7) southeastern Idaho; (8) northern Nevada; (9) northern Utah; (10) southeastern California, the stratotype area of the *gracilitatis* and *haugi* zones; (11) Russkii Island, the stratotype area of the Russian and Ayaxian substages; (12) western Guangxi province; (13) Guizhou province; (14) central Nepal; (15) Salt Range; (16) Mangyshlak Peninsula.

ites, and *Anasibirites* species are especially characteristic of the *tardus* Zone.

The upper Olenekian spans four zones of index species *Bajarunia euomphala, Nordophiceras contrarium, Parasibirites grambergi*, and *Olenekites spiniplicatus*. Parastratotype of this substage is selected at the Divnyi Creek in the Chernokhrebetnaya River basin, the eastern Taimyr (Dagys and Sobolev, 1995). Stratotype of the *euomphala* Zone is located at the Buur River in lower courses of the Olenek River. Stratotypes of the *contrarium* and *grambergi* zones are established in the eastern Taimyr, and that of the *spiniplicatus* Zone is defined at the Mengilyakh Creek.

Genera *Bajarunia* and *Boreoceras* are characteristic of the *euomphala* Zone. Distribution of their species enabled the unit subdivision into the *Bajarunia eiekitensis, Boreoceras planorbis*, and *B. demokidovi* subzones, the first of which yields only the index species *B. eiekitensis* (Popow). In the *planorbis* Zone, its index species *B. planorbis* Dagys et Ermakova coexists with *Bajarunia alexandri* Dagys and with rare specimens of B. taimyrensis Dagys and *Pseudosageceras* sp. The index species *Boreoceras demokidovi* (Kiparisova) and associated *Bajarunia euomphala* (Keyserling) are typical of the *demokidovi* Zone. First specimens of *Koninckitoides posterius* (Popow) also appear at this level.

The *contrarium* Zone begins at the appearance level of *Nordophiceras, Epiboreoceras*, and *Evenites* genera. It also restricts stratigraphic range of *Praesibirites* forms and is subdivided into three *Epiboreoceras lenaense, Praesibirites tuberculatus*, and *P. egorovi* subzones. Taxa characteristic of the *lenaense* Subzone are its index species *E. lenaense* (Dagys et Konstantinov) and associated *E. mirabile* (Dagys et Ermakova), *Nordophiceras contrarium* (Popow), and *Evenites* forms. Last specimens of *K. posterius* occur here as well. In the *tuberculatus* Subzone, its index species *P. tuberculatus* (Dagys et Konstantinov) coexists with *N. contrarium*. The *egorovi* Subzone yields two ammonoid forms only: *P. egorovi* Dagys et Ermakova and *N.* aff. *contrarium*, the latter likely representing a new species.

The lower boundary of the *grambergi* Zone marks the first occurrence level of *Parasibirites* and *Subolenekites* forms. This zone is divided into the *Parasibirites kolymensis, P. mixtus*, and *P. efimovae* subzones. The first subzone yields its index species *P. kolymensis* Bytschkov in association with *Nordophiceras menense* (Popow) and *Subolenekites pilaticus* (Tozer). The lower boundary of *mixtus* Subzone corresponds to the appearance level of *Parasibirites grambergi* (Popow), *P. mixtus* (Popow), *P. subpretiosus* (Popow), *Byrrangoceras taimyrense* Dagys, and *Sibirites elegans* Dagys et Ermakova. Ammonoids characteristic of the *efimovae* Subzone are *Parasibirites efimovae* Bytschkov, *Sibirites pretiosus* (Mojsisovics), *Nordophiceras kazakovi* Dagys et Ermakova, and *Olenekoceras levigatum* Dagys et Ermakova. *Subolenekites altus* (Mojsisovics) and *Boreomeekoceras keyserlingi* (Mojsisovics) also appear at this level.

The *spiniplicatus* Zone is terminal one in the Olenekian Stage. Its lower boundary marks the appearance level of *Olenekites, Pseudosvalbardiceras, Timoceras*, and *Arctomeekoceras* genera. The ammonoid assemblage characterizing this zone is most diverse among other Olenekian assemblages known from Siberia. In addition to genera mentioned above, it includes *Nordophiceras, Boreomeekoceras, Svalbardiceras, Subolenekites, Olenekoceras, Sibirites, Keyserlingites, Prosphingites*, and *Pseudosageceras*. The *spiniplicatus* Zone is subdivided into *Sibirites eichwaldi, Prosphingites czekanowskii*, and *Svalbardiceras spitzbergense* subzones. Beside the index species *S. eichwaldi* (Keyserling), the first subzone yields *Olenekoceras middendorffi* (Mojsisovics), *O. nikitini* (Mojsisovics), *Nordophiceras karpinskii* (Mojsisovics), *N. schmidti* (Mojsisovics), *Pseudosvalbardiceras sibiricum* (Mojsisovics), and some species inherited from the underlying deposits (*B. keyserlingi* and *S. altus*). Ammonoids from the overlying *czekanowskii* Subzone are of a similar taxonomic composition, though their assemblage is distinct because of appearance of *Prosphingites* and *Keyserlingites* genera. The genus *Svalbardiceras* and index species *S. spitzbergense* (Frebold) appear in the next *spitzbergense* Subzone, where some species of genera *Prosphingites, Olenekites, Nordophiceras*, and *Keyserlingites* are known as well.

Canadian equivalents of the lower and upper Olenekian of Siberia are the Smithian and Spathian stages termed after the Smith and Spath creeks of the Ellesmere Island (Tozer, 1967, 1994a, 1994b).

The northwestern part of the Ellesmere Island is the stratotype area of the Smithian Stage. The stage corresponds here to an upper portion of the Smith Creek Member coupled with lower beds of the Svartfjeld Member of the Blind Fiord Formation. It includes the *Hedenstroemia hedenstroemi, Euflemingites romunderi*, and *Anawasatchites tardus* zones.

As is mentioned before, the *hedenstroemi* Zone and its stratotype were originally distinguished in Siberia. In Canada, the reference section of the zone is situated at the Griesbach Creek, the Axel Heiberg Island, where it yields no other ammonoids except for the zonal index species. The *hedenstroemi* Zone is also known in the Ellesmere Island, where its paleontological characterization is similarly poor.

The type exposure of the *romunderi* Zone is located at the Smith Creek. Ammonoids of this zone are known as well from the Axel Heiberg Island and British Columbia. They represent genera *Kashmirites, Melagathiceras, Juvenites, Thermalites, Gyronites, Prionolobus, Meekoceras, Euflemingites, Anaxenaspis, Arctoceras, Paranannites, Oxyussuria*, and *Pseudosageceras*.

In the Toad River stratotype (northeastern British Columbia), deposits underlying the *tardus* Zone are

barren of well-preserved ammonoids. At the Smith Creek (Ellesmere Island) and along the Liard River (northeastern British Columbia), this zone overlies the *romunderi* Zone. The *tardus* Zone also known in the Axel Heiberg Island yields representatives of genera *Kashmirites, Xenoceltites, Arctoceras?, Paranannites?, Anasibirites, Prionites, Wasatchites, Anawasatchites, Arctoprionites*, and *Pseudosageceras*.

The Spathian Stage stratotype at the Spath Creek (Ellesmere Island) corresponds to an upper portion of the Svartfjeld Member that is composed of alternating shale, siltstone, and sandstone beds terminating the Blind Fiord Formation. The stage is subdivided into the *Subolenekites pilaticus* and *Keyserlingites subrobustus* zones. The lower one is distinguished in the Axel Heiberg Island, where it yields *Arctomeekoceras obtusum* Tozer, *Neomeekoceras scalariforme* Tozer, *Subolenekites pilaticus* (Tozer), *S. subtilis* (Tozer), and *Pseudosageceras* sp. The upper zone established in the Ellesmere Island, where its stratotype is located, is also known in the northeastern British Columbia. Ammonoid genera occurring in this zone are *Sulioticeras, Isculitoides, Zenoites, Popovites, Monacanthites, Prosphingites, Cordillerites, Metadagnoceras, Procarnites, Olenekites, Svalbardiceras, Keyserlingites*, and *Leiophyllites*.

Deposits of the lower Olenekian *Meekoceras gracilitatis* Zone are quite widespread *in the western United States*. They are known in Alaska, northeastern Washington, southwestern Montana, southeastern Idaho, northwestern Nevada, northern Utah, and eastern California. In most localities, the *gracilitatis* Zone corresponds to a thin, probably condensed horizon of limestone and coquina. Ammonoids of this zone are so diverse as nowhere else over the globe, the Lower Triassic of the United States inclusive. The zone yields representatives of genera *Dieneroceras, Hemiaspenites, Flemingites, Anaflemingites, Euflemingites, Pseudoceltites, Xenoceltites, Preflorianites, Cordillerites, Pseudaspidites, Owenites, Inyoites, Paranannites, Prosphingitoides, Juvenites, Thermalites, Parussuria, Metussuria, Lanceolites, Pseudohedenstroemia, Anahedenstroemia, Aspenites, Meekoceras, Wyomingites, Arctoceras, Arctoprionites*, and *Pseudosageceras* (Hyatt and Smith, 1905, Smith, 1932, Kummel and Steele, 1962).

Next stratigraphic level corresponds to the *Anasibirites* Zone that is most distinct in northern Utah, near the Fort Douglas (Mathews, 1929; Smith, 1932), where it yields *Pseudosageceras, Cordillerites, Xenoceltites, Meekoceras, Anasibirites, Hemiprionites, Wasatchites*, and *Gurleyites* species. In southeastern Idaho, the Lower Shale of the Thaynes Formation, which occur at the same level, yield representatives of *Hemiprionites, Gurleyites, Anasibirites, Wasatchites*, and *Anawasatchites* genera (Kummel, 1954). The shale rests here on the Lower Limestone bearing *M. gracilitatis* White.

One of the most complete sections of the lower Olenekian is situated in southeastern Idaho, neat the Bear Lake. Four biostratigraphic levels, namely the *Tirolites, Columbites, Procolumbites*, and *Prohungarites* beds, have been distinguished here in the Thaynes Formation above the Lower Shale corresponding to the *Anasibirites* Zone (Smith, 1932; Kummel, 1954, 1969; Orchard and Tozer, 1997). The lower beds (220 m) correspond to the Middle Limestone bearing *Tirolites harti* Smith and *Dalmatites attenuatus* Smith. The Middle Shale of the next level (45 m) yields genera *Columbites, Pseudosageceras, Cordillerites, Subvishnuites, Xenoceltites, Preflorianites, Pseudaspidites, Pseudoceltites, Svalbardiceras, Nordophiceras, Procolumbites, Bajarunia, Boreoceras, Tirolites, Hellenites, Dalmatites*, and *Ussurites*. The upper part of these *Columbites* Beds has been recently distinguished as an individual unit—the *Procolumbites* Beds, though the list of their ammonoid taxa is unpublished yet. Finally, a member of limestones and shales that is situated 300 m above the *Procolumbites* Beds and yields *Prohungarites, Pseudosageceras, Isculitoides, Epiceltites, Stacheites, Keyserlingites*, and *Olenekites* species is distinguished as the *Prohungarites* Beds.

Several localities of late Olenekian ammonoids are known in northwestern Nevada, where, at the Mt. Tobin, seven new ammonoid species have been defined at the level of 10–15 m above the Tobin Formation base. The assemblage from this level includes *Subcolumbites, Paragoceras, Stacheites, Isculitoides, Ussurites, Metadagnoceras*, and *Hemilecanites* forms. Not far away from this locality, basal beds of the same formation yield *Subcolumbites, Pseudosageceras, Hellenites*, and *Prehungarites* species (Kummel, 1969; Silberling and Wallace, 1969). Despite some difference in taxonomic composition, both assemblages characterize the same biostratigraphic level, i.e., *Subcolumbites* Beds correlative with the *Prohungarites* Beds in Idaho.

Next biostratigraphic level of North American sections is represented by the *Neopopanoceras haugi* Zone. This zone was originally distinguished in the Inyo Mountains of southeastern California (Hyatt and Smith, 1905), although relationships between this and conjugate zones below and above it were unclear at that time. According to initial interpretation, ammonoids of the *haugi* Zone represent a mixed assemblage consisting of the late Olenekian and Anisian forms, and the zone has been attributed to the basal Anisian. This viewpoint was acknowledged for a long period, but Silberling with colleagues doubted it in the latest 1960s (Silberling and Tozer, 1968; Silberling and Wallace, 1969). They reported on poorly preserved ammonite resembling a *Keyserlingites* form that was found few meters above the base of the *haugi* Zone in the Inyo Mountains, the stratotype area of the zone. Discussing distribution of ammonoids in the Humboldt Range of northwestern Nevada, they also demonstrated that this zone is sandwiched here between the Olenekian *Subcolumbites* Beds and *caurus* Zone that was regarded at

that time as the lowermost in the Anisian Stage of the western United States. Later on, new biostratigraphic levels of the Anisian were distinguished in the same section. These were the *Japonites welteri, Pseudokeyserlingites guexi*, and *Silberlingites mulleri* beds (Bucher, 1989), and the *haugi* Zone got the place between the *Subcolumbites* and *J. welteri* beds.

After the revision (Bucher, 1989), list of ammonoid taxa from the *haugi* Zone included the following species: *Neopopanoceras haugi* (Hyatt et Smith), *Pseudacrochordiceras inyoense* (Smith), *Subhungarites yatesi* (Hyatt et Smith), *Keyserlingites subrobustus* (Mojsisovics), *Metadagnoceras pulchrum* Tozer, *Preflorianites* sp., *Olenekites* sp., *Isculitoides* sp., *Inyoceras multicameratum* (Smith), *I. bittneri* Bucher, and *Hemilecanites* sp. This assemblage is of the Olenekian affinity, and I share the Bucher's opinion, considering the *haugi* Zone as the uppermost biostratigraphic unit of the Lower Triassic in the western United States.

In southern Primor'e, the Lower Triassic deposits are exposed along coastlines of the Amurskii and Ussuriiskii bays, in the Maikhe River basin, and in the Russkii Island. More than 100 ammonoid species representing about 70 genera have been described from these exposures (Zakharov, 1997b). The Olenekian deposits are divided here into the Tobizin and Chernyshev horizons, stratotypes of which are established in the Russkii Island (Burii *et al.*, 1976).

The Tobizin Horizon includes the *Hedenstroemia bosphorensis* and *Anasibirites nevolini* zones. Stratotype of the former is situated between the Ayaks Bay and Cape Balka, where it is composed of sandstone (50–60 m) intercalated with coquina lentils and thin siltstone interlayers. The zone is subdivided into the *Gyronites separatus* and *Euflemingites prynadai* beds. The *G. separatus* Beds yield ammonoids representing genera *Gyronites, Ambites, Parahedenstroemia, Hedenstroemia, Meekoceras, Juveniles, Proharpoceras, Cordillerites*, and *Koninckites*. Species identified in the *E. prynadai* Beds represent genera *Koninckites, Hedenstroemia, Meekoceras, Juvenites, Pseudosageceras, Pseudohedenstroemia, Epihedenstroemia, Ussuria, Parussuria, Metussuria, Arctoceras, Dieneroceras, Anaxenaspis, Ambites, Prionolobus, Owenites, Prosphingitoides, Anakashmirites, Paranannites, Inyoites, Eophyllites, Hemiprionites, Gurleyites, Preflorianites, Flemingites*, and *Euflemingites*.

The *nevolini* Zone is exposed in the northern coast of the Paris Bay, Cape Zhitkov, and Tobizin Peninsula, where its section is composed of sandstone (16.8 m) with rare limestone lentils and siltstone interlayers. The type section at the left bank of the Artemovka River (northern coast of the Ussuriiskii Bay) is composed of siltstone and shale beds (12.5–15.5 m) intercalated with lentils of calcareous sandstone. The latter yield representatives of genera *Meekoceras, Parahedenstroemia, Arctoceras, Owenites, Prosphingitoides, Juvenites, Prionolobus, Arctoprionites, Mangyshlakites, Hemilecanites, Hemiprionites, Palaeokazakhstanites, Anasibirites, Wasatchites, Gurleyites, Burijites*, and *Subalbanites*.

The Chernyshev Horizon begins with the *Tirolites–Amphistephanites* Zone. Rocks of the latter are exposed along the Paris Bay northern coast and in the Tobizin Peninsula and Cape Schmidt, where the zone section (40 m) is composed of sandstone enclosing lentils of sandy coquina and limestone. The zone corresponds to the Schmidt Formation, stratotype of which is established in the Cape Schmidt (Zakharov, 1997a) and includes the *Bajarunia dagysi* and *Tirolites ussuriensis* beds (15 and 25 m thick, respectively). The former yield *B. dagysi* Zakharov, *Bandoites tobisinensis* (Kiparisova), and *B. pacificus* (Zharnikova), whereas the latter bear *T. ussuriensis* Zharnikova, *Tchernyschevites subdalmatus* (Zharnikova), *Kazakhstanites sonticus* (Zakharov), *K. zakharovi* (Zharnikova), and *K. nicolai* (Diener). Species *Tchernyschevites costatus* Zakharov, *Bandoites elegans* Zakharov, *Amphistephanites parisensis* (Zakharov), and *Tirolites subcassianus* Zakharov are distributed throughout the zone.

Next *Neocolumbites insignis* Zone is composed, in its stratotype at the northwestern coast of the Chernyshev Bay, of shale and siltstone beds (60 m) intercalated with sandstone interlayers. Abundant limy and marly concretions occurring in the beds yield ammonoids of genera *Pseudosageceras, Neocolumbites, Svalbardiceras?, Khvalynites, Procolumbites, Olenekoceras, Hellenites, Columbites, Leiophyllites, Preflorianites*, and *Tirolites*.

The Chernyshev Horizon, like the entire Lower Triassic of Primor'e, is crowned with the *Subcolumbites multiformis* Zone. In the Cape Zhitkov, stratotype of the latter (19 m) is composed of shale with interlayers of sandstone and sandy limestone. These rocks yield ammonoids of genera *Pseudosageceras, Zhitkovites, Columbites, Isculitoides?, Paragoceras, Epiboreoceras, Subcolumbites, Prenkites, Preflorianites, Leiophyllites*, and *Palaeophyllites*. The *insignis* and *multiformis* zones characterize the Zhitkov Formation that has stratotype in the Cape Zhitkov.

The Tobizin Horizon coupled with the Schmidt Formation represent the local Ayaxian Substage, stratotype of which is situated between the Ayaks and Paris bays. The Zhitkov Formation is equivalent to the local Russian Substage having stratotype in the northwestern coast of the Chernyshev Bay (Zakharov, 1997a).

In China, the Olenekian Stage begins with the *Hubeitoceras lingyunense* Zone, characteristic taxa of which are genera *Pseudosageceras, Prionolobus, Paranorites, Koninckites, Mesohedenstroemia, Proptychites, Flemingites, Xenodiscoides, Kashmirites, Lingyunites*, and *Hubeitoceras*. Being originally distinguished as the *Koninckites lingyunensis* Zone of the Loulou Formation in the west of the Guangxi province (Chao, 1959), this unit was established later on in the Jiangsu and Anhui provinces, where its ammonoids are

mostly represented by *Flemingites* species (Wang and He, 1980).

Higher in the section, there are the *Owenites costatus* and *Anasibirites kingianus* zones distinguished in the same formation. The *costatus* Zone is distinct because of an extraordinary diversity of ammonoids. In the western Guangxi, it yielded more that 100 species, which represent genera *Pseudosageceras, Latisageceras, Cordillerites, Meekoceras, Owenites, Prosphingitoides, Paranorites, Koninckites, Clypeoceras, Dieneroceras, Juvenites, Inyoites, Kashmirites, Anakashmirites, Pseudoceltites, Xenoceltites, Preflorianites, Lanceolites, Ussuria, Pseudohedenstroemia, Mesohedenstroemia, Hanielites, Pseudaspidites, Flemingites, Euflemingites, Subvishnuites, Proptychites, Aspinites, Paranannites, Proharpoceras*, and *Tuyangites*. Analogues of the *costatus* Zone are known in the southern and eastern Tibet, and also in the central Qinghai, northwestern Sichuan, and northern Guizhou provinces (Wang and He, 1976, 1980, 1981). Ammonoid genera identified in the *kingianus* Zone (originally the *Pseudowenites oxynotus* Zone) are *Anasibirites, Xenoceltites, Preflorianites, Subflemingites, Pseudaspidites, Owenites, Pseudowenites, Metussuria, Juvenites*, and *Meekoceras*. Concurrent deposits in the central Qinghai yield *Anasibirites, Anakashmirites, Pseudoceltites, Subvishnuites, Pseudosageceras*, and *Platussuria* forms (He *et al.*, 1986). The zone under consideration is also known in the northern Qinghai, Jiangsu, Anhui, and Hubei provinces (Wang and He, 1980).

The overlying *Tirolites* Beds have been distinguished in platform deposits of the Sichuan, Guizhou, Yunnan, and Qinghai provinces (Wang, 1985). Ammonoid genera characterizing them are *Tirolites, Dinarites, Dalmatites, Dorikranites?*, and *Hololobus*. According to their distribution, the beds are divided into the *Tirolites* and *Dinarites* zones.

The *Subcolumbites* Beds located higher in the section have been originally distinguished by Chao as the *Columbites costatus* Zone in three exposures of the western Guangxi province. Later on, the *Subcolumbites asymmetricus* Zone was placed at this level (Wang and He, 1980). The *Subcolumbites* Beds yield a diverse assemblage of ammonoids, list of which includes, after revision by Kummel (1969), the following genera: *Hemilecanites, Proptychitoides, Procarnites, Paragoceras, Pseudoprosphingites, Tunglanites, Subcolumbites, Paradinarites, Prenkites, Dagnoceras*, and *Hellenites*. Equivalent beds are known in the Qinghai province and in the eastern Kunlun Mountains (He *et al.*, 1986; Wang and Yang, 1992).

The *Procarnites–Ziyunites–Japonites* Zone is terminal one in the Lower Triassic of China. It yields mixed assemblages of the late Olenekian and early Anisian ammonoid genera *Pseudosageceras, Cordillerites, Xenoceltites, Preflorianitoides, Albanites, Procarnites, Proptychitoides, Pseudoprosphingites, Isculitoides, Metadagnoceras, Tunglanites, Nordophiceras, Parussuria, Eophyllites, Leiophyllites, Eodanubites, Eoacrochordiceas, Procladiscites, Japonites*, and *Ziyunites* (Kummel, 1969; Wang, 1978; Wang and He, 1980). Fossil ammonoids are usually confined to thin (0.1–0.2 m) limestone beds, which likely accumulated during a period of condensed sedimentation. Ammonoid burials of this kind are known in the Guizhou, Sichuan, Qinghai provinces and in southern Tibet.

An interesting section of the Lower Triassic is known in the Marsyangdi River upper courses, *central Nepal* (Waterhouse, 1994, 1996a, 1996b), where very diverse ammonoids are poorly preserved to my regret. The *Arctoceras chuluense* Waterhouse Beds represent here an equivalent of the lower Olenekian. They occur at the top of the limy–shaly Kangla Member (0.5 m) that is either the terminal unit in the Khangsar Formation, or the basal one in the Nar Formation of clayey shales and red dolomites. Alternating shale and dolomite beds represent the basal portion (1–2 m) of the last formation. Its middle part (11 m) consists of shales with rare dolomite interlayers, and the upper one (11 m) again is composed of alternating dolomite and shale beds. The lower subdivision of the Nar Formation that is distinguished as the range zone of *Nordophiceras erbeni* bears ammonoid genera *Anakashmirites, Eukashmirites, Metinyoites, Preflorianites, Pseudoceltites, Nordophiceras, Kymatites, Meekoceras, Jolinkia, Anasibirites, Rohillites, Wyomingites*, and *Pseudohedenstroemia* (*Jolinkia jeanneti* Subzone). Ammonoids from the middle part represent genera *Latisageceras, Anakashmirites, Eukashmirites, Nilgeria, Preflorianites, Arctoceras, Pseudoceltites, Nordophiceras, Kymatites, Anasibirites, Subflemingites, Pseudohedenstroemia*, and *Lanceolites* (*Nilgeria manangensis* Subzone). Genera *Pseudosageceras, Anakashmirites, Eukashmirites, Preflorianites, Pseudoceltites, Nordophiceras, Anasibirites, Prionites, Flemingites, Rohillites, Euflemingites, Anaflemingites, Arctoceras, Eophyllites, Pseudaspidites?*, and *Pseudohedenstroemia* (*Eophyllites obliqueplicatus* Subzone) are characteristic of the upper part.

The overlying Pisang Formation is composed of greenish siltstones and black shales (12 m), all bearing dispersed specimens of *Xenoceltites* sp., *Preflorianites kummeli* Waterhouse, *Paranannites pisangi* Waterhouse, and *Rohillites?* sp. This ammonoid assemblage characterizes *P. kummeli* Subzone closely interrelated with the underlying *erbeni* Zone.

The Naurchuli Member is basal one in the next Gungdang Formation. It is composed of gray to orange-red dolomites (0.72 m), which yield genera *Anakashmirites, Eukashmirites, Pseudoceltites, Kazakhstanites, Nordophiceras, Meekoceras, Jolinkia, Anasibirites, Paranannites, Flemingites, Rohillites*, and *Euflemingites*. The summary range of the Nar and Pisang formations, and of the Naurchuli Member corresponds to the Gangapurnan Stage.

that time as the lowermost in the Anisian Stage of the western United States. Later on, new biostratigraphic levels of the Anisian were distinguished in the same section. These were the *Japonites welteri, Pseudokeyserlingites guexi,* and *Silberlingites mulleri* beds (Bucher, 1989), and the *haugi* Zone got the place between the *Subcolumbites* and *J. welteri* beds.

After the revision (Bucher, 1989), list of ammonoid taxa from the *haugi* Zone included the following species: *Neopopanoceras haugi* (Hyatt et Smith), *Pseudacrochordiceras inyoense* (Smith), *Subhungarites yatesi* (Hyatt et Smith), *Keyserlingites subrobustus* (Mojsisovics), *Metadagnoceras pulchrum* Tozer, *Preflorianites* sp., *Olenekites* sp., *Isculitoides* sp., *Inyoceras multicameratum* (Smith), *I. bittneri* Bucher, and *Hemilecanites* sp. This assemblage is of the Olenekian affinity, and I share the Bucher's opinion, considering the *haugi* Zone as the uppermost biostratigraphic unit of the Lower Triassic in the western United States.

In southern Primor'e, the Lower Triassic deposits are exposed along coastlines of the Amurskii and Ussuriiskii bays, in the Maikhe River basin, and in the Russkii Island. More than 100 ammonoid species representing about 70 genera have been described from these exposures (Zakharov, 1997b). The Olenekian deposits are divided here into the Tobizin and Chernyshev horizons, stratotypes of which are established in the Russkii Island (Burii *et al.*, 1976).

The Tobizin Horizon includes the *Hedenstroemia bosphorensis* and *Anasibirites nevolini* zones. Stratotype of the former is situated between the Ayaks Bay and Cape Balka, where it is composed of sandstone (50–60 m) intercalated with coquina lentils and thin siltstone interlayers. The zone is subdivided into the *Gyronites separatus* and *Euflemingites prynadai* beds. The *G. separatus* Beds yield ammonoids representing genera *Gyronites, Ambites, Parahedenstroemia, Hedenstroemia, Meekoceras, Juveniles, Proharpoceras, Cordillerites,* and *Koninckites.* Species identified in the *E. prynadai* Beds represent genera *Koninckites, Hedenstroemia, Meekoceras, Juvenites, Pseudosageceras, Pseudohedenstroemia, Epihedenstroemia, Ussuria, Parussuria, Metussuria, Arctoceras, Dieneroceras, Anaxenaspis, Ambites, Prionolobus, Owenites, Prosphingitoides, Anakashmirites, Paranannites, Inyoites, Eophyllites, Hemiprionites, Gurleyites, Preflorianites, Flemingites,* and *Euflemingites.*

The *nevolini* Zone is exposed in the northern coast of the Paris Bay, Cape Zhitkov, and Tobizin Peninsula, where its section is composed of sandstone (16.8 m) with rare limestone lentils and siltstone interlayers. The type section at the left bank of the Artemovka River (northern coast of the Ussuriiskii Bay) is composed of siltstone and shale beds (12.5–15.5 m) intercalated with lentils of calcareous sandstone. The latter yield representatives of genera *Meekoceras, Parahedenstroemia, Arctoceras, Owenites, Prosphingitoides, Juvenites, Prionolobus, Arctoprionites, Mangyshlakites, Hemilecanites, Hemiprionites, Palaeokazakhstanites, Anasibirites, Wasatchites, Gurleyites, Burijites,* and *Subalbanites.*

The Chernyshev Horizon begins with the *Tirolites–Amphistephanites* Zone. Rocks of the latter are exposed along the Paris Bay northern coast and in the Tobizin Peninsula and Cape Schmidt, where the zone section (40 m) is composed of sandstone enclosing lentils of sandy coquina and limestone. The zone corresponds to the Schmidt Formation, stratotype of which is established in the Cape Schmidt (Zakharov, 1997a) and includes the *Bajarunia dagysi* and *Tirolites ussuriensis* beds (15 and 25 m thick, respectively). The former yield *B. dagysi* Zakharov, *Bandoites tobisinensis* (Kiparisova), and *B. pacificus* (Zharnikova), whereas the latter bear *T. ussuriensis* Zharnikova, *Tchernyschevites subdalmatus* (Zharnikova), *Kazakhstanites sonticus* (Zakharov), *K. zakharovi* (Zharnikova), and *K. nicolai* (Diener). Species *Tchernyschevites costatus* Zakharov, *Bandoites elegans* Zakharov, *Amphistephanites parisensis* (Zakharov), and *Tirolites subcassianus* Zakharov are distributed throughout the zone.

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The Chernyshev Horizon, like the entire Lower Triassic of Primor'e, is crowned with the *Subcolumbites multiformis* Zone. In the Cape Zhitkov, stratotype of the latter (19 m) is composed of shale with interlayers of sandstone and sandy limestone. These rocks yield ammonoids of genera *Pseudosageceras, Zhitkovites, Columbites, Isculitoides?, Paragoceras, Epiboreoceras, Subcolumbites, Prenkites, Preflorianites, Leiophyllites,* and *Palaeophyllites.* The *insignis* and *multiformis* zones characterize the Zhitkov Formation that has stratotype in the Cape Zhitkov.

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The *Subcolumbites* Beds located higher in the section have been originally distinguished by Chao as the *Columbites costatus* Zone in three exposures of the western Guangxi province. Later on, the *Subcolumbites asymmetricus* Zone was placed at this level (Wang and He, 1980). The *Subcolumbites* Beds yield a diverse assemblage of ammonoids, list of which includes, after revision by Kummel (1969), the following genera: *Hemilecanites, Proptychitoides, Procarnites, Paragoceras, Pseudoprosphingites, Tunglanites, Subcolumbites, Paradinarites, Prenkites, Dagnoceras*, and *Hellenites*. Equivalent beds are known in the Qinghai province and in the eastern Kunlun Mountains (He *et al.*, 1986; Wang and Yang, 1992).

The *Procarnites–Ziyunites–Japonites* Zone is terminal one in the Lower Triassic of China. It yields mixed assemblages of the late Olenekian and early Anisian ammonoid genera *Pseudosageceras, Cordillerites, Xenoceltites, Preflorianitoides, Albanites, Procarnites, Proptychitoides, Pseudoprosphingites, Isculitoides, Metadagnoceras, Tunglanites, Nordophiceras, Parussuria, Eophyllites, Leiophyllites, Eodanubites, Eoacrochordiceas, Procladiscites, Japonites*, and *Ziyunites* (Kummel, 1969; Wang, 1978; Wang and He, 1980). Fossil ammonoids are usually confined to thin (0.1–0.2 m) limestone beds, which likely accumulated during a period of condensed sedimentation. Ammonoid burials of this kind are known in the Guizhou, Sichuan, Qinghai provinces and in southern Tibet.

An interesting section of the Lower Triassic is known in the Marsyangdi River upper courses, *central Nepal* (Waterhouse, 1994, 1996a, 1996b), where very diverse ammonoids are poorly preserved to my regret. The *Arctoceras chuluense* Waterhouse Beds represent here an equivalent of the lower Olenekian. They occur at the top of the limy–shaly Kangla Member (0.5 m) that is either the terminal unit in the Khangsar Formation, or the basal one in the Nar Formation of clayey shales and red dolomites. Alternating shale and dolomite beds represent the basal portion (1–2 m) of the last formation. Its middle part (11 m) consists of shales with rare dolomite interlayers, and the upper one (11 m) again is composed of alternating dolomite and shale beds. The lower subdivision of the Nar Formation that is distinguished as the range zone of *Nordophiceras erbeni* bears ammonoid genera *Anakashmirites, Eukashmirites, Metinyoites, Preflorianites, Pseudoceltites, Nordophiceras, Kymatites, Meekoceras, Jolinkia, Anasibirites, Rohillites, Wyomingites*, and *Pseudohedenstroemia* (*Jolinkia jeanneti* Subzone). Ammonoids from the middle part represent genera *Latisageceras, Anakashmirites, Eukashmirites, Nilgeria, Preflorianites, Arctoceras, Pseudoceltites, Nordophiceras, Kymatites, Anasibirites, Subflemingites, Pseudohedenstroemia*, and *Lanceolites* (*Nilgeria manangensis* Subzone). Genera *Pseudosageceras, Anakashmirites, Eukashmirites, Preflorianites, Pseudoceltites, Nordophiceras, Anasibirites, Prionites, Flemingites, Rohillites, Euflemingites, Anaflemingites, Arctoceras, Eophyllites, Pseudaspidites?*, and *Pseudohedenstroemia* (*Eophyllites obliqueplicatus* Subzone) are characteristic of the upper part.

The overlying Pisang Formation is composed of greenish siltstones and black shales (12 m), all bearing dispersed specimens of *Xenoceltites* sp., *Preflorianites kummeli* Waterhouse, *Paranannites pisangi* Waterhouse, and *Rohillites?* sp. This ammonoid assemblage characterizes *P. kummeli* Subzone closely interrelated with the underlying *erbeni* Zone.

The Naurchuli Member is basal one in the next Gungdang Formation. It is composed of gray to orange-red dolomites (0.72 m), which yield genera *Anakashmirites, Eukashmirites, Pseudoceltites, Kazakhstanites, Nordophiceras, Meekoceras, Jolinkia, Anasibirites, Paranannites, Flemingites, Rohillites*, and *Euflemingites*. The summary range of the Nar and Pisang formations, and of the Naurchuli Member corresponds to the Gangapurnan Stage.

Distinguished higher in the sequence are the following units: the Drakar Member of granular limestone bearing *Ampletimoria welteri* (0.6 m), the Bodzo Member of coquinoid limestone with *Kariceltites manangensis* (0.4–0.6 m), the Kone Member of foliated limestone that yields *Eophyllites giganteus* in association with *Albanites* and *Xenoceltites* forms (2.28 m), and the Langpo Member of black and white coquinoid limestones bearing *Keyserlingites costatus* (1.6 m). Description of ammonoid assemblages characterizing these members has not been published yet. Their summary range corresponds to the local Mesokantoan Stage.

In the Salt Range of Pakistan, the lower Olenekian boundary is inside the Ceratite Sandstone (15–30 m), a constituent of the Mittiwali Member. This unit yields large *Flemingites* shells and bellerophontids of the genus *Stachella*. The *Stachella* Beds divide the unit in two parts, the lower of which bears ammonoids of the Induan Stage (Shevyrev, 1999). Ammonoids from *Stachella* Beds represent genera *Flemingites, Rohillites, Pseudoflemingites, Clypeoceras, Paraspidites, Eoptychites, Fuchsites. Koninckites, Waagenoproptychites, Paranorites, Parakymatites, Parastephanites, Pseudoceltites, Kashmirites, Anakashmirites*, and *Xenodiscoides*. Rocks above these beds yield genera *Flemingites, Clypeoceras, Prionites, Xenoceltites, Pseudoceltites, Xenodiscoides, Preflorianites, Pseudohedenstroemia, Paranorites*, and *Beoflemingites* (Waagen, 1895; Kummel and Steele, 1962; Waterhouse, 1996a). Not long ago, the Pakistani–Japanese research group divided the Ceratite Sandstone of the Salt Range into the *Paranorites* and *Flemingites* zones (Ali *et al.*, 1985). Sharing their viewpoint, I place the lower Olenekian boundary between these zones.

The Mittiwali Member is crowned with the upper Ceratite Limestone (17–50 m) so that a half of the member is composed of limestone, and the rest of shales and sandstone. Ammonoids from basal part of the member represent genera *Pseudosageceras, Eukashmirites, Parakymatites, Arctoceras*, and *Meekoceras*. Genera *Anasibirites, Meekoceras, Eophyllites, Pseudoceltites, Xenoceltites, Anakashmirites, Wasatchites, Hemiprionites, Juvenites, Stephanites*, and *Pijaconcha* occur higher in the section. Guex (1978) divided the upper Ceratite Limestone into the *Meekoceras gracilitatis* and *Anasibirites pluriformis* zones.

The next Narmia Member corresponds to that part of the section, in which Waagen distinguished the bivalve-bearing and dolomitic beds underlying the Upper Limestone. The lowermost interval (3 m) is composed of limestone, locally coquinoid, and the middle one (30–60 m) is represented by shales intercalated with dolomitic limestone. Pisolitic limestone (1.5–2.3 m) and massive dolomite (0.8–3.0 m) are characteristic rocks of the upper subunit. Genera *Pseudosageceras, Subvishnuites, Xenoceltites, Procarnites, Isculitoides, Anakashmirites, Svalbardiceras, Dagnoceras, Stacheites, Nordophiceras, Arctomeekoceras, Tirolites, Columbites, Prohungarites*, and *Paranoritoides*, which characterize the *Tirolites–Columbites* Zone have been determined in the bivalve-bearing beds (Kummel, 1966; Guex, 1978). The Upper Limestone yields ammonoid genera *Tozericeras, Prohungarites, Epiceltitoides, Pseudosageceras, Palaeophyllites*, and *Pseudoharpoceras* characteristic of the *Tozericeras pakistanum* Zone (Guex, 1978).

Only the late Olenekian ammonoids are known from the *Mangyshlak Peninsula*. They occur in a thick (about 1000 m) sequence of sand and clay intercalated with interlayers and lentils of dark gray limestone. These rocks represent the Tyurupa Group that is subdivided into the clayey Tartali and sandy Karadzhatyk formations. The most complete section of the Tyurupa Group is exposed in the northern slope of the Karatauchik Ridge, near the Dolnapa Wells. Four biostratigraphic levels are distinguishable here (Shevyrev, 1990):

(1) *Doricranites* Beds (80 m) of gray shale, yellowish brown when weathered and intercalated with sandstone and limestone interlayers; fourteen limestone interlayers yielded ammonoids *Doricranites bogdoanus* (Buch) and *D. acutus* (Mojsisovics).

(2) *Kiparisovites–Tirolites* Beds (230 m) of gray shale, greenish when weathered, enclosing interlayers of sandstone, limestone, and spheroid limy concretions; genera *Kiparisovites, Hyrcanites*, and *Tjurupites* occur at four levels in the lower one third of the sequence, and abundant *Tirolites cassianus* (Quenstedt) were found in association with rare *Kiparisovites* forms at eight levels higher in the section.

(3) *Columbites–Dinarites* Beds (220 m) of gray shale, greenish when weathered, bearing rare limy nodules, and intercalated with limestone and thin sandstone interlayers; this part of the sequence yields most diverse ammonoids. Species of genera *Pseudosageceras, Xenoceltites, Preflorianites, Khvalynites, Columbites, Procolumbites, Mangyshlakites, Hellenites, Albanites, Kazakhstanites, Leiophyllites, Kashmirites, Tirolites, Dinarites*, and *Procarnites* have been found here at 25 levels.

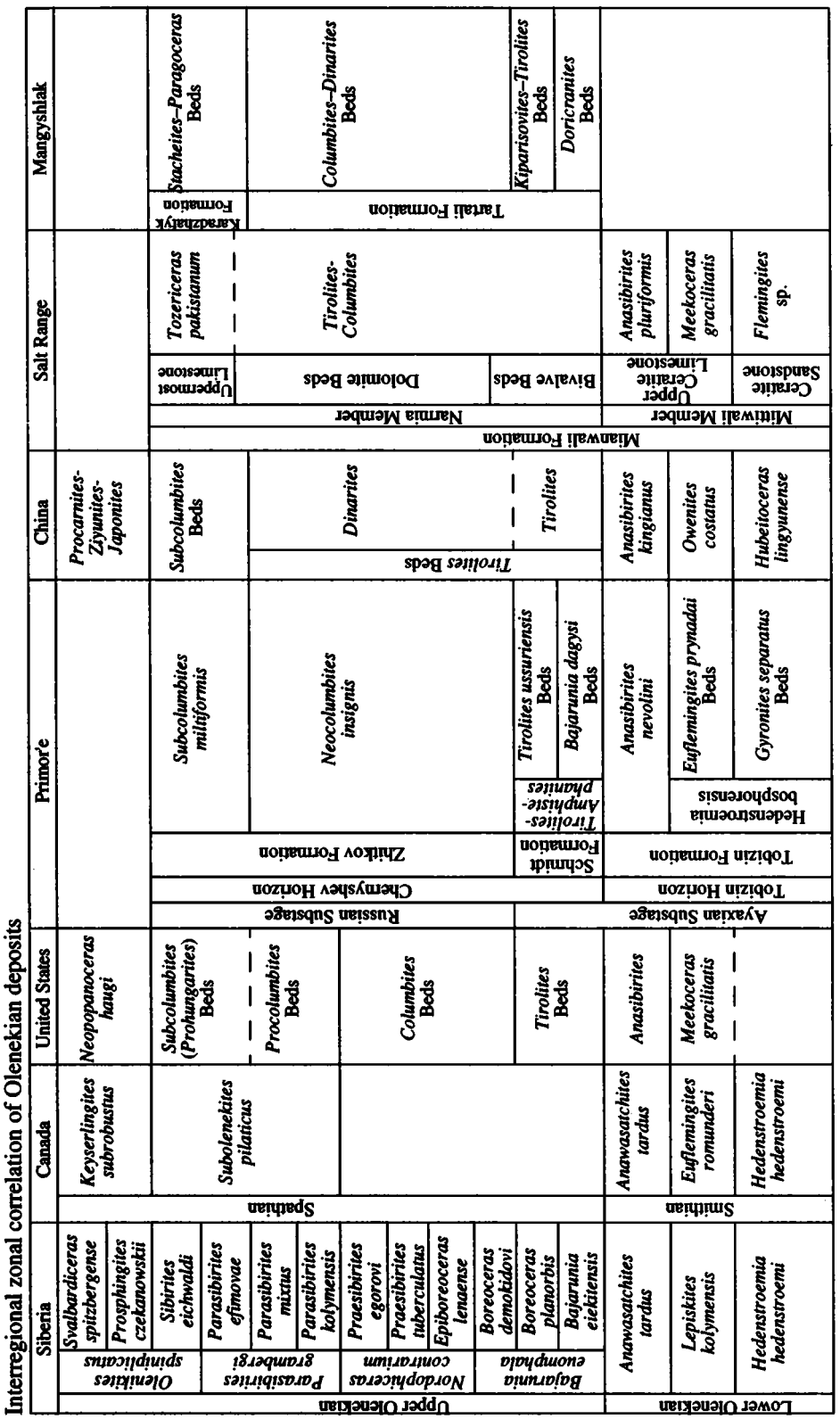
(4) *Stacheites–Paragoceras* Beds (380 m) of light gray sandstone and greenish gray sandy shale with rare limestone lentils and interlayers; 16 levels with abundant *Stacheites* shells associated with rare *Paragoceras* and single *Mangyshlakites* forms are established in this unit.

Three lower units correspond to the Tartali Formation, and the upper one represents the Karadzhatyk Formation.

CORRELATION OF REGIONAL SCHEMES

Zonal assemblages of early Olenekian ammonoids can be correlated quite easily because of their insignificant geographic differentiation (see the table). The *hedenstroemi* Zone of Siberia and Canada corresponds

Interregional zonal correlation of Olenekian deposits



to the *Gyronites separatus* Beds of Primor'e (basal interval of the *bosphorensis* Zone), in which first *Hedenstroemia* forms appear. Their analogues are the *lingyunense* Zone of China, which yields abundant *Flemingites* forms, and the *Flemingites* sp. Zone of the Salt Range. The *kolymensis* Zone of Siberia is correlative with the *romunderi* Zone of Canada, as they both bear genera in common, such as *Euflemingites, Meekoceras, Arctoceras, Juvenites*, and *Melagathiceras.* The same genera are also known from the *gracilitatis* Zone of the United States, and the latter can be regarded as a chronological equivalent of the *kolymensis* and *romunderi* zones. In turn, the American *gracilitatis* Zone is correlative with the *Euflemingites prynadai* Beds of Primor'e (upper portion of the *bosphorensis* Zone) and with the *costatus* Zone of China. Their interconnection is indicated by many genera in common, such as *Meekoceras, Owenites, Dieneroceras, Juvenites, Inyoites, Ussuria, Pseudohedenstroemia, Euflemingites, Flemingites, Prosphingitiodes*, and others. The same stratigraphic level corresponds to the *gracilitatis* Zone of the Salt range. Terminal one in the lower Olenekian of Siberia is the *tardus* Zone, characteristic genera of which are *Anasibirites, Anawasatchites*, and *Xenoceltites.* Its equivalent in Canada is the synonymous zone bearing the same genera. This very level is represented by *Anasibirites* Zone in the United States, by *nevolini* Zone in Primor'e, by *kingianus* Zone in China, and by *pluriformis* Zone in the Salt Range, since they all yield genera *Anasibirites, Wasatchites, Anawasatchites*, and *Hemiprionites.*

The clear correlation between the lower Olenekian ammonoid zones is dimmed however in concurrent deposits of Nepal. In contrast to other regions of the world, where *Flemingites* levels regularly predate those of *Anasibirites* forms, the succession of early Olenekian ammonoids seems to be overturned in Nepal. Because of this anomaly, it is impossible to insert the Nepalese zonation into the general correlation scheme. Waterhouse (1996b, p. 161) suggested that similar faunas of the mid-early Triassic time could asynchronously appear in different regions. His explanation contradicts however the available data implying a uniform global strategy of Triassic ammonoids evolution. It is likely therefore that the abnormal distribution of Nepalese ammonoids is a consequence of erroneous geological observations.

Another anomaly of the Nepalese ammonoid succession is the lowered stratigraphic level of the genus *Nordophiceras.* Outside Nepal, this genus appears in the upper Olenekian only, and data on its earlier appearance in Nepal seems to be a result of a misleading paleontological determination. Species *Nordophiceras erbeni* Waterhouse from this country has narrower umbilicus and shorter lateral lobe in distinction from typical representatives of this genus. It is remarkable as well that the early Triassic ammonoids from Nepal are very poorly preserved, and I share opinion of paleontologists from the University of Milan who rightly noted in their comments to the work by Waterhouse (1994) that classification and correlation of ammonoids should be based on a valid fossil materials, which should be clearly pictured therewith.

The upper Olenekian deposits can be quite simply correlated within the Boreal province. The Spathian Stage of Canada begins with the *pilaticus* Zone. Its index species *Subolenekites pilaticus* is identified as well in the *kolymensis* Subzone of Siberia (the lower one in the *grambergi* Zone). In accord with this data, Dagys (1997, 1999) suggested that the *pilaticus* Zone is chronologically equivalent to the *kolymensis* Subzone. However, the former yields species *Arctomeekoceras obtusum* and *Neomeekoceras scalariforme.* In Siberia, genus *Arctomeekoceras* appears at the level of the *eichwaldi* Subzone (the lower one in the *spiniplicatus* Zone) that yields as well the genus *Neomeekoceras*, a younger synonym of the genus *Pseudosvalbardiceas* in opinion of Dagys (1997, p. 217). Accordingly, the *pilaticus* Zone of Canada should be correlated with the *grambergi* Zone coupled with the *eichwaldi* Subzone of Siberia. The next *subrobustus* Zone of Canada is clearly correlative with the summary interval of *czekanowskii* and *spitzbergense* subzones. They all yield not only *Keyserlingites subrobustus* but also three genera in common: *Prosphingites, Olenekites*, and *Svalbardiceras.* The presented comparison implies that analogues of Siberian *euomphala* and *contrarium* zones are missing in Canada (see the table).

Correlation of upper Olenekian deposits inside the Tethyan province is also obvious. The *Tirolites, Columbites*, and *Procolumbites* beds of the United States are distinctly correlative with the *Tirolites–Amphistephanites* and *Neocolumbites insignis* zones of Primor'e, and also with the *Dorikranites, Kiparisovites–Tirolites*, and *Columbites–Dinarites* beds of Mangyshlak. All these subdivisions yield genera *Tirolites, Columbites*, and *Procolumbites.* The *Tirolites* Beds of China and a greater part of the *Tirolites–Columbites* Zone of the Salt Range correspond most likely to the same stratigraphic interval. The overlying *Subcolumbites (Prohungarites)* Beds of the United States appear to be equivalent to the *Subcolumbites multiformis* Zone of Primor'e and to *Subcolumbites* Beds of China. Genera in common from these units are *Subcolumbites* and *Paragoceras.* An upper part of the *Tirolites–Columbites* Zone and the entire *Tozericeras pakistanum* Zone of the Salt Range, which yield *Prohungarites, Isculitoides*, and *Stacheites* forms known in the *Subcolumbites* Beds of the United States, also fit the level under consideration. The *Stacheites–Paragoceras* Beds of Mangyshlak probably represent one more unit fitting it. The *haugi* Zone terminating the Lower Triassic sequence in the western Unites States seems to be correlative with the *Procarnites–Ziyunites–Japonites* Zone of China, with the lower Ceratite Limestone of the central Himalayas, and with lower limestone beds in Timor, which yield an assemblage of mixed late Olenekian–early Anisian ammonoids.

It is difficult, however, to establish unambiguous correlation between the late Olenekian ammonoid zonations of Boreal and Tethyan regions, because taxa in common for both biogeographic provinces are rare. The genus *Bajarunia* detected in the *Tirolites–Amphistephanites* Zone of Primor'e suggests its interconnection with the *euomphala* Zone of Siberia. Genera *Bajarunia* and *Boreoceras* offer possibility to correlate the former zone with the *Columbites* (and *Tirolites*) Beds of the United States. *Nordophiceras* forms present in the *Columbites* Beds point to their correlation with the Siberian *contrarium* Zone. Species *Svalbardiceras sheldoni* Kummel characterizing that part of the sequence in Idaho, which is attributed now to the *Procolumbites* Beds, actually represents genus *Neomeekoceras* (Tozer, 1994a, p. 71) known from the *pilaticus* Zone of Canada. In the *insignis* Zone of Primor'e, genera *Columbites* and *Procolumbites* coexist with *Olenekoceras* forms, which appear for the first time in the *grambergi* Zone of Siberia. Accordingly, the *insignis* Zone can be correlated with the *Columbites–Procolumbites* Beds of the United States and with the *euomphala* (top portion) and *grambergi* zones of Siberia.

The interregional correlation of the North American *Subcolumbites* (*Prohungarites*) Beds and *haugi* Zone is debatable so far. Dagys (1994, 1997) argued, till the end of his days, for the traditional viewpoint that the *Subcolumbites* beds represent an equivalent of the Canadian *subrobustus* Zone terminal in the Olenekian Stage, and that the *haugi* Zone is basal one in the Anisian Stage. His opponents (Silberling and Tozer, 1968; Silberling and Wallace, 1969; Guex, 1978; Bucher, 1989; Tozer, 1994b) believe that the *haugi* Zone is an analogue of the *subrobustus* Zone, and their opinion seems to be better substantiated by recent data. *Keyserlingites subrobustus* that has been described from the *haugi* Zone is the index species of synonymous zone in Canada. The concurrent range of both zones is emphasized by genera *Metadagnoceras, Isculitoides*, and *Olenekites* present in them. In addition, they yield the same conodont species (Orchard and Tozer, 1997). In distinction from true representatives of the genus, *Keyserlingites bearriverensis* Kummel and *K. bearlakensis* Kummel described from the *Prohungarites* Beds of Idaho have lateral tubercles and simple shorter protuberances in the ventral lobe (Kummel, 1969). They likely represent a new genus. *Olenekites* cf. *spiniplicatus* (Mojsisovics) that was found in the same beds probably belongs to the genus *Subolenekites* known from the Canadian *pilaticus* and Siberian *grambergi* zones. In addition, the *Subcolumbites* Beds of Nevada yield the conodont species *Neospathodus* aff. *taimyrensis* (Orchard and Tozer, 1997) that is close in morphology to *N. taimyrensis* Dagys from the *grambergi* Zone of Siberia (Dagys, 1984). Accordingly, the *Subcolumbites (Prohungarites)* Beds can be considered as chronologically correlative, to a certain extent, with the last zone and with the basal portion of the *spiniplicatus* Zone.

* * *

Even glancing at the table of interregional correlation of Olenekian deposits, one can easily understand that the ammonoid zonation established in Siberia is very complete and much more detailed than regional schemes elaborated for other regions of the world. In addition to three zones distinguished in the lower Olenekian, the Siberian scheme includes four upper Olenekian zones subdivided into twelve subzones, all bearing distinctive ammonoid assemblages. This scheme can be rightly considered as biochronological standard not of the Boreal province only (Zakharov *et al.*, 1997), but of the globe as well. It represents a remarkable result achieved by Russian experts in the field of Triassic geology in the second half of 20th century.

Ammonoid zones of the scale are of a variable correlation potential that is especially great in the case of lower Olenekian *hedenstroemi, kolymensis*, and *tardus* zones, chronological equivalents of which are easily recognizable in Boreal and Tethyan sections. Except for Canada, the global correlation of many upper Olenekian zones is less obvious owing to a high geographic differentiation of ammonoids in sea basins of that time. Nevertheless, rare taxa in common from the Boreal and Tethyan provinces elucidate correlation between the upper Olenekian zones of Siberia and concurrent biostratigraphic subdivisions of the United States, Primor'e, China, Salt Range, Mangyshlak, and other regions of the world.

Reviewers V.A. Zakharov and A.G. Konstantinov

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Correlation of Different-Facies Triassic Deposits of the Eastern Urals and Siberia

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Abstract—Some Triassic key sections of Siberia and the eastern Urals are characterized in terms of paleontology. In the northeastern Siberia, these are sequences of the Cape Tsvetkov (the eastern Taimyr Peninsula) and the Ust'-Anabar and Buur–Olenek structural–facies zones. Marine and continental deposits of these sections contain six palynological assemblages of the Induan, Olenekian, late Anisian, Ladinian–early Carnian, Carnian, and early Norian ages. The dating is supported by marine fauna identifications. Analogous palynological assemblages were detected in volcano–sedimentary coastal-marine Triassic sequences recovered by the Tyumen' superdeep borehole and by deep Nikol'skaya-1 borehole in West Siberia. In the eastern Urals, the palynological assemblages of similar composition were found in continental volcano–sedimentary coal-bearing sequences of the Chelyabinsk and Anokhino grabens. This allows correlation of the different-facies Triassic deposits. Distribution patterns of the distinguished spore–pollen and macrofossil plant assemblages are compared for the first time. The correspondence between evolutionary stages of Triassic taphofloras in East Siberia and the eastern Urals is established.

Key words: eastern Urals, West and East Siberia, Triassic, biostratigraphy, palynological assemblages, correlation.

In the vast region extending from the eastern Urals to the northern part of East Siberia, Triassic deposits are represented by sediments of different genesis. In the north of East Siberia, these are coastal-marine, marine, and volcano–sedimentary deposits. In isolated depressions of the eastern Urals, Triassic continental sequences are composed of volcano–sedimentary deposits in the lower part and of predominantly lacustrine sandy siltstone and mudstone beds enclosing coal seams of commercial value in the upper part. Boreholes drilled In West Siberia recovered Triassic volcanic, volcanogenic–sedimentary, coastal-marine, and continental deposits in some graben–rift structures (Surkov *et al.*, 1997).

Extensive stratigraphic investigations in the indicated regions refined lithostratigraphy and marine biostratigraphy of the Triassic deposits (Kazakov *et al.*, 1982; Mogucheva, 1982, 1984, 1986; Dagys and Kazakov, 1984; *Obshchaya...*, 1984; Obonitskaya, 1986; Kulikova, 1989; Romanovskaya, 1989; *Trias...*, 1990; Kirichkova, 1993; *Zonal'nye...*, 1994; Mogucheva and Betekhtina, 1998).

The Triassic stratigraphic scale accepted in the USSR (*Obshchaya...*, 1984) and the Mesozoic biozonation standard elaborated for Siberia (Zakharov *et al.*, 1997) are based on evolution of marine fauna. Biostratigraphic subdivision and, especially, correlation and dating of Triassic continental deposits devoid of marine fauna are problematic. We believe that the problem can be solved by means of comprehensive study of particular fossils, such as spores and pollen of terrestrial plants, which are the least facies-dependent. They are perfectly preserved in continental, coastal-marine, and marine facies. These fossils may have a decisive role in a long-distance correlation of different-facies deposits.

Objects of our investigations were continental, coastal-marine, and marine deposits of the eastern Urals, West Siberia, and northern East Siberia. The continental deposits are characterized everywhere by plant remains and palynological assemblages. The spore and pollen also occur in marine deposits bearing zonal ammonoid species. In addition to our results, analysis of data obtained by other researchers enabled the interregional correlation and more precise dating of Triassic continental units.

Comprehensive studies of spores and pollen from the Triassic deposits of northern East Siberia began in the 1950s. Initial data on composition and stratigraphic ranges of miospores were published by Kara-Murza (1960) and Korotkevich (1963, 1968, 1970). Later on, the miospores were studied by Klimko (1986), Kulikova (1989), Romanovskaya (1989), and Krugovykh (1996). Triassic plant remains were analyzed by Shvedov (1960), Sadovnikov (Sadovnikov *et al.*, 1981, Sadovnikov and Orlova, 1990), Mogucheva (1982, 1984, 1986; *Trias...*, 1990; Mogucheva and Betekhtina, 1998) in East Siberia, and by Krishtofovich and Prinada (1933), Vladimirovich (1959, 1965, 1967), Kirichkova

(1962, 1969, 1990a, 1990b, 1993; *Novoe...*, 1980) in the eastern Urals. Tuzhikova (1985) and Kurzhebekova (Tuzhikova and Kurzhebekova, 1973) studied Triassic miospores in the eastern Urals.

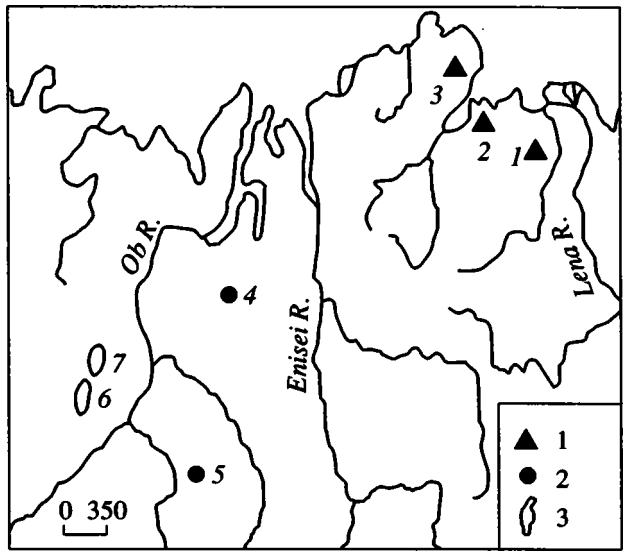
Oleinikov and his colleagues made an attempt to work out a correlation scheme of Triassic continental deposits in Asiatic regions of Russia (*Zonal'nye...*, 1994). They used paleobotanical data (including palynological ones), which existed at that time, though without revision of taxonomic composition of floral taphocoenoses and their stratigraphic ranges. Their scheme appeared essentially analogous to stratigraphic schemes for the continental Triassic of Siberia, which were adopted by Interdepartmental stratigraphic conferences in 1981 and 1991.

In the last years, new data were obtained on spore–pollen assemblages from the Triassic key sections of the northern East Siberia and on biostratigraphy of Triassic deposits penetrated by the Tyumen' superdeep borehole (TSB-6) in West Siberia (Kirichkova *et al.*, 1999). The taxonomic composition of Triassic flora from the eastern Urals has been revised (Kirichkova, 1990a, 1990b). The work done substantiated correlation of Triassic continental and transitional continental–marine deposits of the eastern Urals and East Siberia.

The most complete Triassic section that was chosen as the reference one for northern East Siberia is located in the Cape Tsvetkov (the eastern Taimyr structural–facies zone, see figure). This section 1400 m thick in total was studied thoroughly enough to be subdivided into fine lithologic and biostratigraphic units (Kazakov *et al.*, 1982; Dagys and Kazakov, 1984; Romanovskaya, 1989; Egorov and Kulikova, 1989). The 3rd Interdepartmental regional conference on Mesozoic and Cenozoic stratigraphy of central Siberia approved the following subdivisions of the Cape Tsvetkov section: the Keshin, Cape Tsvetkov, East Taimyr, Ystanakh, Pribrezhnaya (Lower Triassic), Morzhovaya, Kul'dima (Middle Triassic), Osipa, Cape Nemtsov, and Tumul (Upper Triassic) formations (*Resheniya...*, 1978).

LOWER TRIASSIC

The Keshin Formation conformably overlies the coal-bearing deposits with Permian cordaitean flora (Table 1). The formation is represented by coastal-marine and continental sediments with rare foraminifers, conchostracans and plant imprints (Kazakov *et al.*, 1982). According to Romanovskaya (1989) and Obonitskaya (1986), the Keshin Formation of the Cape Tsvetkov contains the *Punctatisporites–Aratrisporites–Nevesisporites* palynological assemblage that was called the Keshin Assemblage (Plate I, figs. 1–6). It is distinguished by the absolute domination of larger forms of the formal genus *Punctatisporites*, i.e., *P. triassicus* Schulz, *P. magnus* Koz., *P. fungosus*

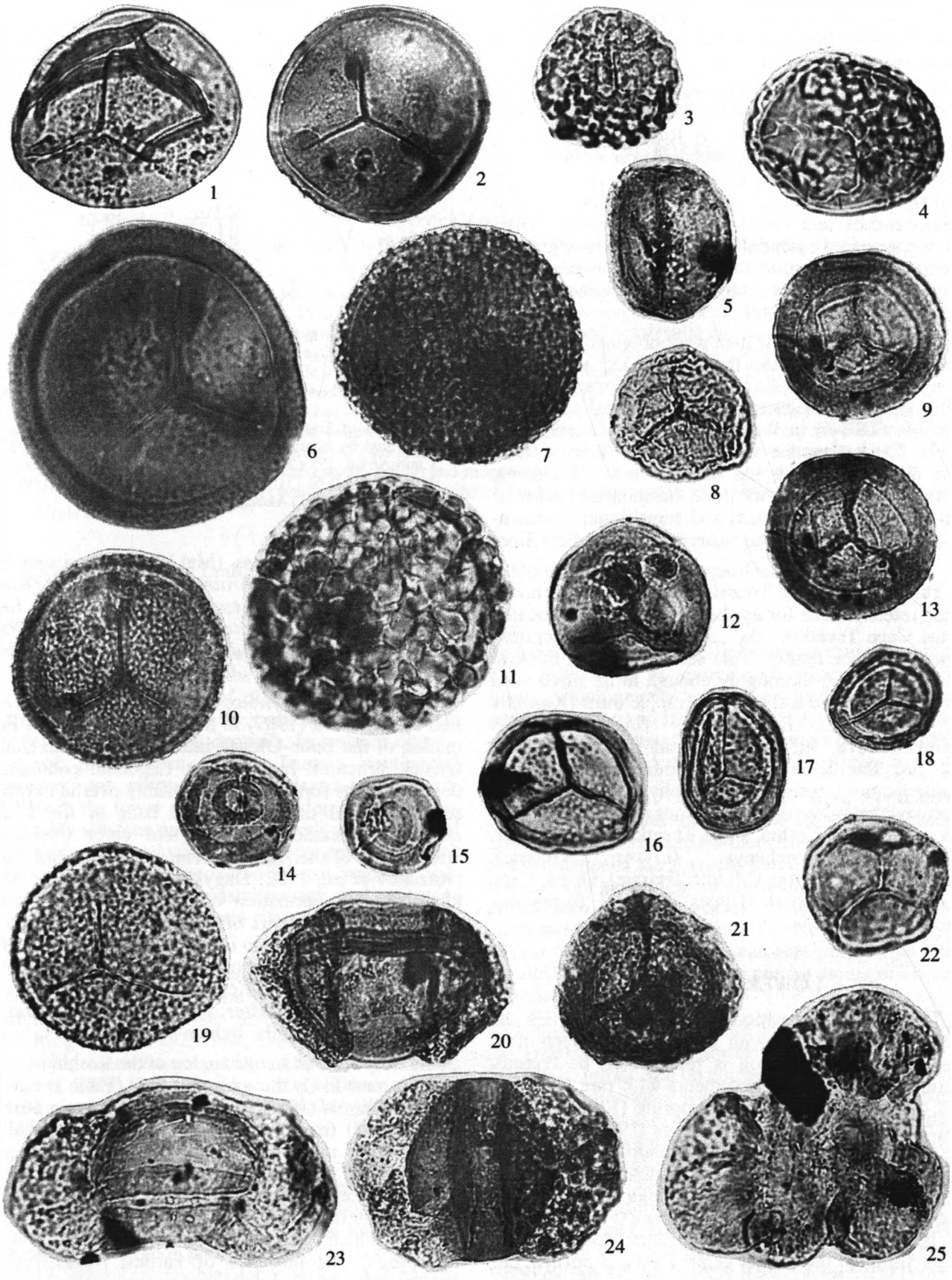


Localities of Triassic reference sections exposed (1) and recovered by boreholes (2): (*1*) Buur–Olenek region, (*2*) Cape Airkat, (*3*) Cape Tsvetkov, (*4*) Tyumen' superdeep borehole (TSB-6), (*5*) borehole Nikol'skaya-1, (*6*) Chelyabinsk graben, and (*7*) Anokhino graben.

Balme, and *P. punctatus* (Mal.) War. Persistent but scarce components are *Aratrisporites spinosus* (Kop.) War., *A. parvispinosus* Lesch., *Rewanispora* sp., *Leptolepidites* sp., *Discisporites microdiscus* (K.-M.) War., *Anaplanisporites stipulatus* Jans., and *Gnetaceapollenites steevesi* Jans.

An analogous palynological assemblage was identified by Kulikova (1989) in the Ulakhan-Yuryakh Formation of the Buur–Olenek interfluve area (the Buur–Olenek structural–facies zone). Lagoonal–continental deposits of the formation conformably overlie Permian sediments and underlie marine beds of the Chekanovskii Formation, which yield early Olenekian ammonoids of the *Hedenstroemia hedenstroemi* Zone (Kazakov *et al.*, 1982; Dagys *et al.*, 1982). The Ulakhan-Yuryakh Formation of the Buur–Olenek zone contains rare fragments of foraminifers. According to the stratigraphic position of the formation between the Permian continental deposits and marine beds of the *hedenstroemi* Zone, the Keshin Assemblage with *Punctatisporites, Aratrisporites*, and *Nevesisporites* can be reliably attributed to the Induan Stage (Table 1).

In West Siberia, an age analog of the Keshin Assemblage is most likely the Assemblage Ia (Table 1) macerated by Klimko (1986) and Krugovykh (see in Surkov *et al.*, 1997) from the lower beds (depth interval of 4432.6–5505 m) of the volcano–sedimentary deposits penetrated by the borehole Nikol'skaya-1 in the northern Omsk area (figure). As noted by these researchers, Assemblage Ia mainly includes the reworked Paleozoic forms, which associate however with Triassic miospores. The presence of earliest *Nevesisporites limatus* Pl. and *Cyathidites brevizadites* Helby indi-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cates its Early Triassic (Induan arbitrarily) age. Moreover, these Triassic forms are common to both the West Siberian Assemblage Ia and the Keshin Assemblage, which is confidently of the Induan age.

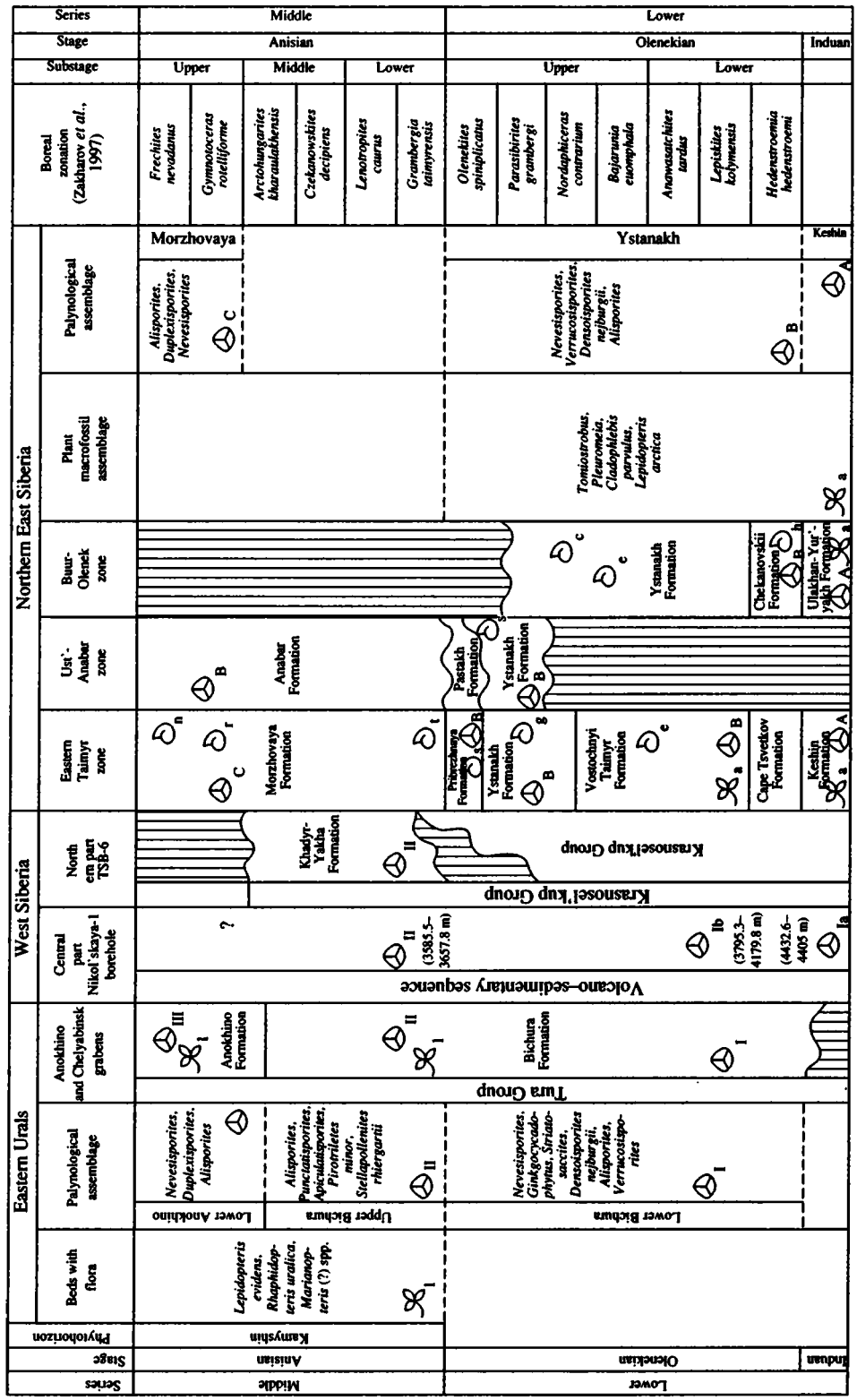
The succeeding Ystanakh palynological assemblage with *Nevesisporites, Verrucosisporites, Densoisporites nejburgii*, and *Alisporites* of the Cape Tsvetkov section characterizes the Eastern Taimyr, Ystanakh and Pribrezhnaya formations containing Olenekian zonal ammonite species (Table 1). A similar assemblage is known from the marine beds of the Ystanakh Formation in the lower course of the Olenek River (the Ust'-Anabar structural–facies zone) and from the Chekanovskii and Ystanakh formations in the Olenek–Buur interfluve area. In these areas, all three formations also enclose zonal ammonoid species of the Olenekian Stage (Table 1). The Ystanakh palynological assemblage from the mentioned subdivisions includes three groups of spores (Plate I, figs. 7–25). The first group of *Nevesisporites* forms is represented by *N. fossulatus* Balme, *N. lumatulus* Playf., *N. pokrovskajae* Rom., and *N. macrogranulatus* Rom. The second group consists of ornamented tubercular forms *Verrucosisporites* Balme, *V. applanatus* Mädl., and *Cyclotriletes* sp. The *Punctatisporites* species of the third group are identical to those of the Keshin Assemblage, but less abundant. Everywhere, the Ystanakh palynological assemblage contains *Densoisporites nejburgii* (Schulz) Balme, *Polycingulatisporites* spp., *Descisporites microdiscus* (K.-M.) War., *Taenisporites novimundi* Jans., *Proprosporites pococki* Jans., *Crustaesporites* sp., and *Alisporites* spp. In general, taxonomic composition of the Ystanakh Assemblage is persistent in vertical and lateral directions. It should be only mentioned that *Triplexisporites playfordii* (de Jersey et Hamilton) Foster was mostly confined to the East Taimyr and Chekanovskii formations, and that abundance of *Alisporites* increases upward in the Cape Tsvetkov section, from the East Taimyr to Pribrezhnaya formations. The Ystanakh Assemblage corresponds either to the Lower Triassic undivided, or to the Olenekian Stage according to occurrence of ammonoids in marine beds of the aforementioned formations (Table 1).

In West Siberia, the lower part of the Triassic section TSG-6 (figure) represents the volcanogenic Korotchaevo Formation (Kazanskii *et al.*, 1995; *Rezul'taty...*, 1995; Kirichkova *et al.*, 1999), palynological characteristics of which is uncertain as yet. In the northern Omsk area, its supposed analog is a basalt sequence with interbeds of red tuffs, mudstones, siltstones, and sandstones recovered by borehole Nikol'skaya-1. Palynological Assemblage Ib (depth interval 3795.3–4179.8 m) is most similar in composition to the Ystanakh assemblage of northern Siberia (Klimko, 1986; Surkov *et al.*, 1997). It is also dominated by diverse cingulate forms of *Nevesisporites*, abundant *Ginkgocycadophytus*, and *Alisporites*. Using this fact, we can consider this palynological assemblage as an age equivalent of the Olenekian Ystanakh palynological assemblage despite of greater diversity of spores of other floral groups (Table 1).

In the eastern Urals, the analogous palynological assemblage is characteristic of the lower half of the volcano–sedimentary Bichura Formation (Table 1) recovered most completely by a series of boreholes in the Chelyabinsk and Anokhino grabens (Tuzhikova and Kurzhebekova, 1973; *Novoe...*, 1980; Tuzhikova, 1985). The Lower Bichura Assemblage of these depressions is known within the limits of the Early Triassic, being of persistent generic and specific composition in spite of variable proportions between taxa in different depressions. Its pollen components are ribbed grains of *Striatosaccites* and bisaccate *Alisporites* and *Ginkgocycadophytus* forms. The spore group includes *Nevesisporites–Densoisporites* spp., *Punctatisporites*, and

Plate I. Early Triassic miospores from northern East Siberia

(1–6) Keshin palynological assemblage: (1) *Punctatisporites leighensis* Playford et Dettmann, specimen no. 728/1, Taas-Eiekit River, Ulakhan-Yuryakh Formation; (2) *Punctatisporites triassicus* Schulz, specimen no. 728/2, Taas-Eiekit River, Ulakhan-Yuryakh Formation; (3) *Rewanispora* sp., specimen no. 730/2, Taas-Eiekit River, Ulakhan-Yuryakh Formation; (4) *Leptolepidites jonkeri* (Jansonius) Jaroshenko et Golubeva, specimen no. 728/2, Taas-Eiekit River, Ulakhan-Yuryakh Formation; (5) *Aratrisporites strigosus* Playford, specimen no. 730/2, Taas-Eiekit River, Ulakhan-Yuryakh Formation; (6) *Punctatisporites fungosus* Balme, specimen no. 8605, Taion-Uiolaakh, Ulakhan-Yuryakh Formation; (7–25) Ystanakh palynological assemblage: (7) *Verrucosisporites pseudomorulae* Visscher, specimen no. 29/3, Kyra-Khos-Teryutteekh, Chekanovskii Formation; (8) *Lundbladispora brevicula* Balme, specimen no. 29/3, Kyra-Khos-Teryutteekh, Chekanovskii Formation; (9, 13) *Densoisporites poatinaensis* Playford, specimen no. 21/2, Taion-Uiolaakh River, Chekanovskii Formation: (9) distal side; (13) proximal side; (10) *Cyclotriletes subgranulatus* Mädler, specimen no. 21/2, Taion-Uiolakh River, Chekanovskii Formation; (11) *Verrucosisporites thuringiacus* Mädler, specimen 21/1, Taion-Uiolaakh River, Chekanovskii Formation; (12) *Densoisporites nejburgii* (Schulz) Balme, specimen no. 24/1, Taion-Uiolakh River, Chekanovskii Formation; (14, 15) *Distalanulisporites reduncti formis* (Korotkevisch) comb. Nov., specimen no. 21/1, Taion-Uiolaakh River, Chekanovskii Formation; (16, 17) *Nevesisporites limatulus* Playford, specimen no. 734/1, Taas-Eiekit River, Ystanakh Formation; (18) *Nevesisporites fossulatus* Balme, specimen no. 734/1, Taas-Eiekit River, Ystanakh Formation; (19) *Verrucosisporites narmianus* Balme, specimen no. 24/1, Taion-Uiolakh River, Chekanovskii Formation; (20) *Taeniaesporites hexagonalis* Jansonius, specimen no. 21/2, Taion-Uiolaakh River, Chekanovskii Formation; (21) *Pechorosporites uniformis* Jaroshenko et Golubeva, specimen no. 21/2, Taion-Uiolaakh River, Chekanovskii Formation; (22) *Retusotriletes radiatus* (K.-M.) Warjuchina, specimen no. 641/1, Nykaabyt River, Ystanakh Formation; (23) *Protohaploxypinus pantii* (Jansonius) Orlowska-Zwolinska, specimen no. 734/1, Taas-Eiekit River, Ystanakh Formation; (24) *Alisporites australis* de Jersey, specimen no. 734/1, Taas-Eiekit River, Ystanakh Formation; (25) *Crustaesporites* sp., specimen no. 734/1, Taas-Eiekit, Ystanakh Formation. Magnification ×600 for all specimens.



$\mathfrak{S}_{a, b}$—fossil plant assemblages of East Siberia; $\mathfrak{S}_{1, 2...}$—fossil plant assemblages of West Siberia and the eastern Urals;

$\Theta_{A, B}$—palynological assemblages of East Siberia; $\Theta_{I, II...}$—palynological assemblages of West Siberia and the eastern Urals; $\Theta_{h, o...}$—zonal ammonoids.

Verrucosisporites. Other permanent components are *Densoisporites nejburgii* Schulz, *D. complicatus* Balme, *Kraeuselisporites* spp., and *Aratrisporites*. Based on these dominants of the Lower Bichura assemblage, we can consider it similar to the Ystanakh assemblage and, hence, can refer it to the Lower Triassic (arbitrarily, to the Olenekian Stage).

MIDDLE TRIASSIC

In the Cape Tsvetkov reference section, the Pribrezhnaya Formation is overlain by the Morzhovaya Formation of mainly marine deposits, which yield Middle Triassic ammonoids (Kazakov *et al.*, 1982; Dagys and Kazakov, 1984).

The lower Morzhovaya Subformation is known to contain early Anisian ammonoids of the *taimyrensis* Zone (Table 1) but no palynological remains.

In West Siberia (the borehole section TSG-6), the volcanogenic Korotchaevo Formation is unconformably overlain by the volcano–sedimentary Khadyr-Yakha Formation (*Rezul'taty...*, 1995; *Tyumenskaya...*, 1996), sedimentary beds of which yielded the Middle Triassic palynological assemblage with *Alisporites, Punctatisporites, Pirotriletes minor* (Mädler) Antonescu, and *Stellapollenites thiergartii* (Mädler) Clement-Westerhof (Kirichkova *et al.*, 1999). An analogous assemblage is known from the depth interval of 3585.5–3657.8 m of the borehole Nikol'skaya-1 (Klimko, 1986; Surkov *et al.*, 1997). It is dominated by spores *Nevesisporites* spp. and by pollen *Alisporites australis* de Jersey. According to Krugovykh, it demonstrates a considerable renewal of the taxonomic composition in comparison with the palynological assemblage of Olenekian age from the depth interval of 3795.3–4189.8 m of the same borehole section. The newly appeared forms are *Duplexisporites gyratus* Playford, *Carnisporites papillatus* Mädl., *Voltziaceaesporites heteromorpha* Klaus, and *Gnetaceaepollenites* sp. Krukhovykh attributed this palynological assemblage to the Anisian.

In the eastern Urals, the Upper Bichura Assemblage is equivalent to the Khadyr-Yakha and Nikol'skaya-II palynological assemblages of West Siberia. This assemblage attributed by Tuzhikova and Kurzhebekova (1973) to the Early Triassic shows predominance of *Alisporites, Platysaccus*, and *Sulcatisporites* pollen and a noticeably reduced amount of *Striatosaccites* pollen. In opinion of Kulikova, *Stellapollenites thiergartii* (Mädler) Clement-Westerhof that was previously identified by Tuzhikova and Kurzhebekova (1973, Plate 18, fig. 1) as *Dacrycarpites* sp. is also present. The spore spectrum includes rare *Nevesisporites* specimens and an increased number of spiny forms belonging probably to the genus *Apiculatisporites*. Kulikova supposes that the Upper Bichura Assemblage includes the characteristic Middle Triassic spores of *Pirotriletes minor* (Mädler) Antonescu identified previously by Tuzhikova and Kurzhebekova (1973, Plate 15, fig. 1) as *Selaginella graniferiformis* Mal.

The comparative taxonomic study allowed us to establish that the Khadyr-Yakha and Upper Bichura palynological assemblages are age equivalence. The characteristic forms *Stellapollenites thiergartii* and *Pirotriletes minor* present in both indicate their Middle Triassic age. According to their stratigraphic position, the Khadyr-Yakha and Upper Bichura formations may correspond to the lower half of the Morzhovaya Formation of the Cape Tsvetkov reference section, in which this level yields lower Anisian ammonites.

The upper Morzhovaya Subformation of the eastern Taimyr key section contains ammonoids of the upper Anisian *rotelliforme* and *nevadanus* zones (Kazakov *et al.*, 1982; Dagys *et al.*, 1984, 1989). Its palynological assemblage with *Alisporites, Duplexisporites*, and *Nevesisporites* forms (Table 1) was first studied by Kulikova. The Morzhovaya Assemblage demonstrates abundance of bisaccate pollen *Alisporites parvus* de Jersey, *Alisporites* sp., *Voltziaceaesporites heteromorpha* Klaus, and *Latosaccus latus* Mädl. Spores are represented by abundant ribbed species *Duplexisporites gyratus* Playf. et Dett., *D. scanicus* (Nilss.) Playf. et Dett., and *Concentricisporites nevessi* Ant. in association with some *Nevesisporites* forms (Plate II, figs. 1–5). In addition, there are *Osmundacidites* spp., *Aratrisporites granulatus* (Klaus) Playf. et Dett., *Microchachryidites dubingeri* Klaus, *Colpectopollis ellipscideus* Viss, and locally abundant monosulcate pollen of *Ginkgocycadophytus*.

Kulikova detected a palynological assemblage analogous to the Morzhovaya one from the upper marine part of the Anabar Formation in the Cape Airkat area of the Ust'-Anabar region (figure, Table 1). The formation bears only fragments of bivalves *Bakevella* ex gr. *arctica* Kipar. (Kazakov *et al.*, 1982; Dagys and Kazakov, 1984).

Palynological assemblages analogous to the Morzhovaya one are unknown from West Siberia. In the borehole section TSG-6, the Khadyr-Yakha Formation is unconformably overlain by the Varenga-Yakha Formation containing the Ladinian–Carnian palynological assemblage (Kirichkova *et al.*, 1999).

In opinion of Kulikova, spores and pollen from the lower part of the Anokhino Formation of the Chelyabinsk and Anokhino grabens in the eastern Urals are similar to those of the Morzhovaya palynological assemblage (Table 1). In the Lower Anokhino Assemblage attributed by Tuzhikova and Kurzhebekova (1973) to the Middle Triassic, spores predominate over pollen. Dominants of the spore group are *Nevesisporites, Descisporites*, ribbed *Duplexisporites*, and spiny *Apiculatisporites* and *Pirotriletes minor*. The less diverse pollen spectrum is represented by monosulcate *Alisporites* and *Stratosaccites*. The taxonomic similarity of the Morzhovaya and Lower Anokhino palynological assemblages suggests their age equivalence and

allows the lower part of the Anokhino Formation to be dated as back as the late Anisian.

The following Kul'dima palynological assemblage from the Cape Tsvetkov reference section is known from the middle and upper subformations of the Kul'dima and Osipa formations (Table 2). The Kul'dima Formation is composed of coastal-marine (lower subformation), shallow marine, fresh-water lagoonal (middle subformation), and fresh-water (upper subformation) sediments (Dagys *et al.*, 1978; Kazakov *et al.*, 1982). The marine sediments yield zonal ammonoid species of the Ladinian Stage (Dagys *et al.*, 1978). The Osipa Formation is represented by silty mudstones and siltstones with ammonoids of the genus *Discophyllites* (Table 2). In the Kul'dima Assemblage (Plate II, figs. 6–15) with *Osmundacidites, Duplexisporites, Annulispora microannulata, Camarozonotriletes rudis*, and *Anapiculatisporites telephorus*, spore species are more diverse than pollen. The most frequent spore forms are *Duplexisporites gyratus* Playf. et Dett., *D. scanus* (Nilss.) Playf. et Dett., *Osmundacidites* sp., and *Annulispora microannulata* (Rag.) Sch., which are accompanied by *Camarozonotriletes rudis* (Lesch.) Klaus, *Cingulatisporites delicatus* Orb.-Zw., *Nevesisporites limatulus* Playf., *Aratrisporites coryliseminis* Klaus, *Anapiculatisporites telephorus* Klaus, *Neoraistrickia* sp., *Alisporites australis* de Jersey, *Microcharyidites* sp., *Triadispora crassa* Klaus, *Stellapollenites thiergartii* (Mädl.), and *Voltziaceaesporites heteromorpha* Klaus (Romanovskaya, 1989).

Kulikova also macerated the Kul'dima Assemblage from continental beds of the middle part of the Gurimis and Chaidakh formations of the Ust'-Anabar region (Table 2). Marine deposits in the lower part of the Gurimis Formation contain early Ladinian ammonoids (Dagys *et al.*, 1978, 1989; Kazakov *et al.*, 1982). The Chaidakh Formation yields early Carnian ammonoids of the genus *Discophyllites*. The taxonomic composition and percentages of main groups in the Kul'dima Assemblage are rather persistent throughout the section and over the distribution area. With due regard for stratigraphic position and coexisting ammonoid fauna, the assemblage can be dated back to the late Ladinian (Table 2).

In West Siberia, the Varenga-Yakha Assemblage from the borehole section TSG-6 (Kirichkova *et al.*, 1999) and palynological Assemblage IV described by Klimko (1986) and Krugovykh (Surkov *et al.*, 1997) from the borehole Nikol'skaya-1 (depth interval 3503–3515.4 m) are equivalents of the Kul'dima Assemblage. The Varenga-Yakha and Nikol'skaya palynological assemblages also show a noticeably increased abundance of the *Leiotriletes* forms, *Osmundacidites* spores, and *Alisporites* pollen parallel to a considerably reduced amount of *Nevesisporites* spores. These taxa are associated with *Duplexisporites, Anapiculatisporites telephorus* (Pautsch.) Klaus, *Cyclotriletes triassicus* Mädl., *Leschikisporites aduncus* (Lesch.) Pot., *Florinites pseudostriatus* Kop., and *Heliosaccus dimorphus* Mädl. The great similarity between the West Siberian and Kul'dima palynological assemblages suggests their correspondence to the upper Ladinian–lower Carnian interval.

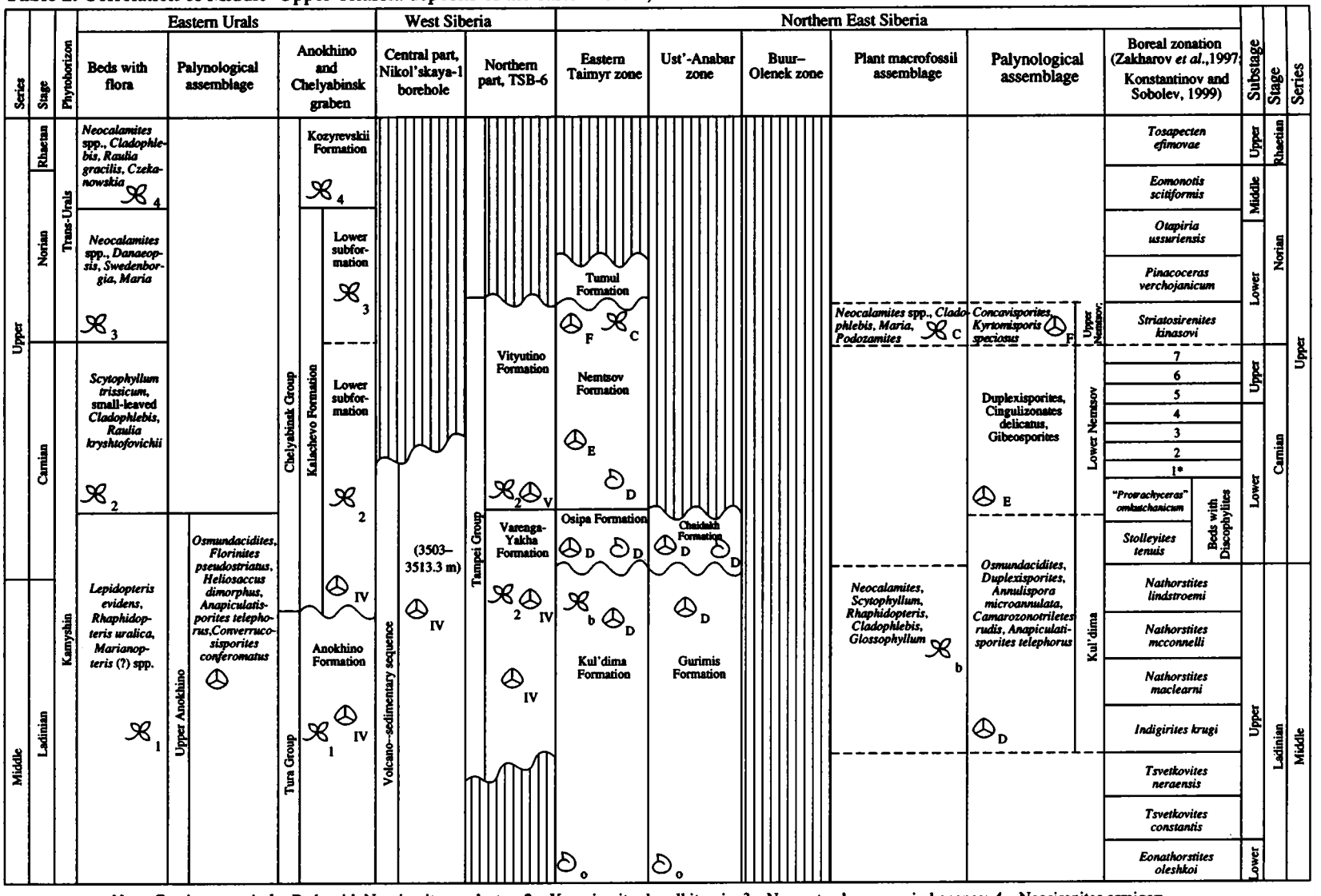
In the eastern Urals, the palynological assemblage from the upper Anokhino and lower Kalachevo subformations of the Chelyabinsk and Anokhino grabens may be also assigned to the Ladinian–Carnian (Table 2). Tuzhikova and Kurzhebekova (1973; *Novoe...*, 1980) who distinguished previously two spore–pollen assemblages from these subdivisions referred the assemblage of the upper Anokhino Subformation to the Middle Triassic and the assemblage of the lower Kalachevo Subformation to the Middle–Late Triassic boundary interval. They noted insignificant taxonomical differences between the assemblages, and taxonomic analysis by Kulikova convinced her that they are almost identical. Accordingly, Kulikova united them into the Upper Anokhino Assemblage. According to Tuzhikova and Kurzhebekova (1973), the original palynological assemblages are dominated by pollen of *Monosulcites, Alisporites, Playsaccus, Triadispora*, and probably *Heliosaccus dimorphus*; the latter two taxa being identified as *Trochosporites* sp. (Plate 24, fig. 13) and *Cordianthus* sp. (Plate 27, fig. 19).

Like the Ladinian–Carnian spore–pollen assemblages of Siberia, the Upper Anokhino Assemblage contains abundant spiny spores *Osmundacidites* spp., *Apiculatisporites parvispinosus* (Lesch.) Schulz, and *Spinotriletes* sp. The overlying basal beds of the Kalachevo Formation yield more abundant *Leiotriletes* specimens and mark the appearance level of spores referable to *Converrucosisporites* aff. *conferornatus* Pautch. Tuzhikova and Kurzhebekova (1973, Plate 26, fig. 5) attributed the latter to Osmundaceae. The Upper Anokhino Assemblage appears to be most similar in composition to the Varenga-Yakha palynological assemblage of West Siberia and may be related to the same stratigraphic interval (Table 2).

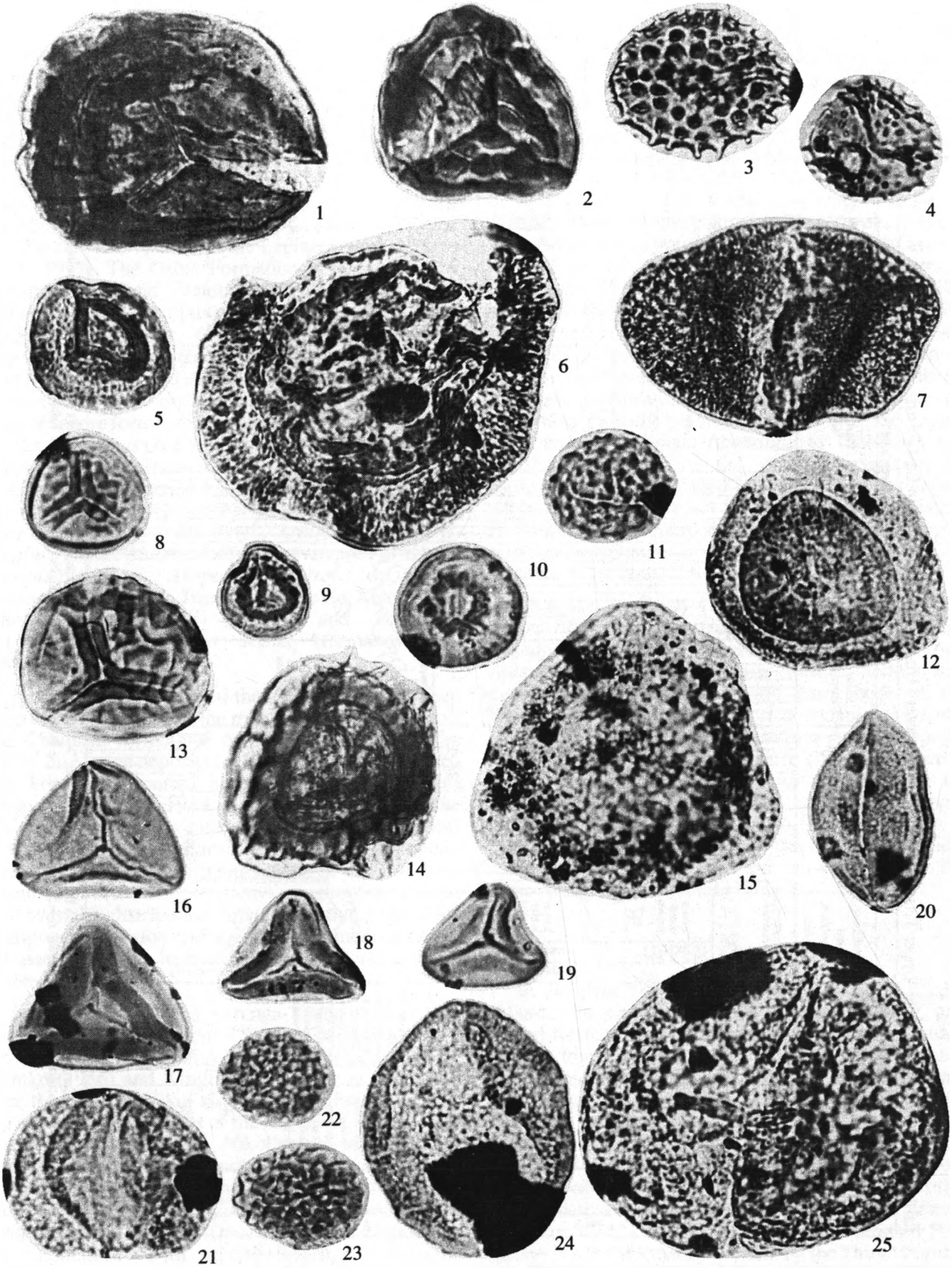
UPPER TRIASSIC

In the Cape Tsvetkov reference section, the Upper Triassic interval corresponds to the Nemtsov and Tumul formations. The Nemtsov Formation is divided into the lower, middle, and upper parts. The lower and middle subformations are represented by marine, coastal-marine and lagoonal sediments. The lower subformation contains early Carnian ammonoids *Discophyllites*, whereas the middle subformation yields only bivalves *Unionites* sp. ind. The upper Nemtsov Subformation is composed of continental, irregularly alternating sandstone and siltstone beds with coal lenses (Kazakov *et al.*, 1982; Dagys, 1984). The Nemtsov Formation is unconformably overlain by the Tumul Formation. The lower and upper spore–pollen assemblages

Table 2. Correlation of Middle–Upper Triassia deposits of the eastern Urals, West and northern East Siberia



Note: Carnian zones*: *1*—Beds with Neosirenites aculeatus; 2—Yanosirenites buralkitensis; *3*—Neoprotrachyceras seimkanense; *4*—Neosirenites armiger; *5*—Yacutosirenites pentastichus: *6*—Sirenites yakutensis; *7*—Striatosirenites kedonensis. For other symbols see Table 1.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have been detected in the middle and upper Nemtsov subformations, respectively.

Taking into account data of Kara-Murza (1960) and Krugovych (1966), one can see that the Lower Nemtsov Assemblage differs from the Kul'dima assemblage by the increased abundance of *Leiotriletes* forms (*Concavisporites* and *Dictyophyllidites*) and reduced percentage of *Osmundacidites* spores. Its permanent components are *Duplexisporites gyratus* Playf. et Dett., *Cingulizonates delicatus* Orl.-Zwd., *Lycopodiacidites keupperi* Klaus, *Limbosporites lundbladii* Nilss., *Anapiculatisporites spiniger* (Lesch.) Reinh., *Chasmatosporites hians* Nilss., *Ch. apertus* Nilss., and *Alisporites* spp. According to the stratigraphic level and presence of early Carnian ammonoids at the base of the lower Nemtsov Subformation, the palynological assemblage under consideration can be assigned to the Carnian Stage.

In West Siberia, the palynological assemblage from basal beds of the Vityutino Formation penetrated by the borehole TSB-6 may be an analog of the Lower Nemtsov Assemblage (Kirichkova *et al.*, 1999). It is also dominated by *Leiotriletes* forms (genera *Concavisporites* and *Osmundacidites*), which associate with *Duplexisporites, Cingulizonates delicatus, Anapiculatisporites spiniger, Camarozonotriletes rudis*, and other forms widespread in the Upper Triassic deposits of Europe (Schulz, 1967).

In the eastern Urals, Triassic deposits overlying lower beds of the Kalachevo Formation are barren of palynomorphs. According to succession and stratigraphic position of palynological assemblages in the Triassic section near Chelyabinsk, we may only suppose that the lower Kalachevo Subformation (excluding its basal part) corresponds to the lower and middle Nemtsov subformations of the Taimyr region.

The Upper Nemtsov Assemblage from synonymous subformation of the Cape Tsvetkov section is of a relatively low species diversity in both the spore and pollen groups (Plate II, figs. 16–25). The abundant *Concavisporites, Leiotriletes*, and *Dictyophyllidites* forms are accompanied by *Kyrtomisporis speciosus* Mädl., *Gibeosporites hirsutus* (Lesch.), *G. lativerrucosus* (Lesch.), *Anapiculatisporites spiniger* (Lesch.) Reich., *Cingulatizonates delicatus* Ol.-Zwd., *Ovalipollis* sp., and *Chasmatosporites hians* Nilss. The Upper Nemtsov Assemblage essentially differs from the lower one, being dominated by diverse *Kyrtomisporis* spores and *Anapiculatisporites spiniger*, which become abundant in the Late Triassic palynofloras of West Europe (Schulz, 1967). This suggests a younger Norian age of the assemblage. In addition, the upper Nemtsov Subformation is unconformably overlain by the Tumul Formation (Table 2) corresponding to the ammonoid *Pinacoceras verchojanicum* Zone (Konstantinov and Sobolev, 1999). For these reasons, the subformation may be of the early Norian age. In West Siberia, equivalents of the Upper Nemtsov Assemblage have not been detected. We do not exclude however that palynological assemblage of this type can be found in the upper part of the Vityutino Formation, the whole range of which may correspond to the Carnian–basal Norian interval.

In the Cape Tsvetkov reference section, Triassic deposits are unconformably overlain by the Lower Jurassic strata (Kazakov *et al.*, 1982). In the borehole section TSB-6 of West Siberia, the Vityutino Formation of the Carnian to possibly early Norian age occurs under the Beregovaya Formation that yields the Early Jurassic palynological assemblage (Kirichkova *et al.*,

Plate II. Middle–Late Triassic miospores from northern East Siberia

(1–5) Morzhovaya palynological assemblage: (1) *Concentricisporites nevesi* Antonescu, specimen no. 107, Cape Tsvetkov, Morzhovaya Formation; (2) *Duplexisporites geratus* Playford et Dettmann, specimen no. 107, Cape Tsvetkov, Morzhovaya Formation; (3) *Spinotriletes* aff. *senecoides* Mädler, specimen no. 107, Cape Tsvetkov, Morzhovaya Formation; (4) *Carnisporites ornatus* Mädler, specimen no. 107, Cape Tsvetkov, Morzhovaya Formation; (5) *Nevesisporites limatulus* Playford, specimen no. 107, Cape Tsvetkov, Morzhovaya Formation; (6–15) Kul'dima palynological assemblage: (6) *Heliosaccus dimorphus* Mädler, specimen no. 135, Cape Tsvetkov, Kul'dima Formation; (7) *Alisporites toralis* (Leschik) Clarke, specimen no. 135, Cape Tsvetkov, Kul'dima Formation; (8) *Camarozonosporites rudis* (Leschik) Klaus, specimen no. 135, Cape Tsvetkov, Kul'dima Formation; (9) *Annulispora microannulata* de Jersey, specimen no. 135, Cape Tsvetkov, Kul'dima Formation; (10) *Annulispora microannulata* de Jersey, specimen no. 10324, Cape Airkat, Chaidakh Formation; (11) *Polypodiites ipsviciensis* (de Jersey) Playford et Dettmann, specimen no. 10323, Cape Airkat, Chaidakh Formation; (12) *Densoisporites* sp. specimen no. 10323, Cape Airkat, Chaidakh Formation; (13) *Camarozonosporites rudis* (Leschik) Klaus, specimen no. 10324, Cape Airkat, Chaidakh Formation; (14) *Cingulizonates delicatus* Orlowska-Zwolinska, specimen no. 10324, Cape Airkat, Chaidakh Formation; (15) *Cingulizonates* aff. *angustus* Semenova, specimen no. 10323, Cape Airkat, Chaidakh Formation; (16–25) Upper Nemtsov palynological assemblage: (16) *Concavisporites* sp., specimen no. 147, Cape Tsvetkov, Nemtsov Formation (upper subformation); (17) *Kyrtomisporis laevigatus* Mädler, specimen no. 149, Cape Tsvetkov, Nemtsov Formation (upper subformation); (18) *Concavisporites toralis* (Leschik) Nilsson, specimen no. 144, Cape Tsvetkov, Nemtsov Formation (upper subformation); (19) *Dictyophyllidites mortoni* (de Jersey) Playford et Dettmann, specimen no. 147, Cape Tsvetkov, Nemtsov Formation (upper subformation); (20) *Chasmatosporites minor* Nilsson, specimen no. 147, Cape Tsvetkov, Nemtsov Formation (upper subformation); (21) *Alisporites* sp., specimen no. 147, Cape Tsvetkov, Nemtsov Formation (upper subformation); (22) *Gibeosporites hirsutus* (Leschik) Leschik, specimen no. 144, Cape Tsvetkov, Nemtsov Formation (upper subformation); (23) *Gibeosporites lativerrucosus* (Leschik) Leschik, specimen no. 147, Cape Tsvetkov, Nemtsov Formation (upper subformation); (24) *Chasmatosporites hians* Nilsson, specimen no. 149, Cape Tsvetkov, Nemtsov Formation (upper subformation); (25) *Brachysaccus neomundanus* (Leschik) Mädler, specimen no. 149, Cape Tsvetkov, Nemtsov Formation (upper subformation). Magnification ×600 for all specimens.

1999). In the borehole section Nikol'skaya-1, Lower Jurassic sediments rest on volcano–sedimentary deposits with the Ladinian–early Carnian spore–pollen assemblage at the top (Surkov *et al.*, 1997).

In the Late Triassic time, sedimentation continued only in the Chelyabinsk graben of the eastern Urals. The Upper Triassic spans here the coal-bearing upper Kalachevo Subformation and the Kozyrevskii Formation with plant remains (Kirichkova, 1993). Regretfully, palynological characteristics of this interval are inadequate. Lists of miospores published without their descriptions by Malyavkina (1964) and Tuzhikova (*Unifitsirovannye...*, 1980) are out of date in terms of taxonomy. Other palynological data (Gluzbar, 1994) on concurrent deposits in the neighboring Bulanash graben cannot be used, because the published generalized lists include many taxa identified in open nomenclature and characterizing a wide stratigraphic range from the Early through Late Triassic.

FOSSIL PLANTS

Fossil plants are irregularly distributed in the Triassic key sections of the regions under consideration. In the Cape Tsvetkov section, they occur in continental and less frequently coastal-marine interbeds, but not throughout the section. In the superdeep borehole section of West Siberia, plant remains are scarce, represented by few taxa occurring mainly in the Varenga-Yakha and Vityutino formations (Kirichkova *et al.*, 1999; Kazakov *et al.*, 2000). The latest list of plant taxa from the depth interval of 4469–3503 m of the borehole section Nikol'skaya-1 (Surkov *et al.*, 1997) is generalized and unsuitable for the purpose of phytostratigraphy. Only Triassic deposits of the eastern Urals, where they are of continental genesis (except for their basal part), are most fully characterized by fossil plants.

Early Triassic plant remains are known only from the Keshin, East Taimyr and Ulakhan-Yuryakh formations of the Taimyr key sections (Table 1). Because of great taxonomic similarity, all the local taphofloras studied by Mogucheva (1982, 1984, 1986; Mogucheva and Betekhtina, 1998) are united into the Keshin assemblage of fossil plants. The latter is dominated by lycopsids *Tomiostrobus* and *Pleuromeia*, which coexist with *Mesenteriophyllum tajmyrense* (Mogutch.) Mogutch., *Neokoretrophyllites annularioides* Radz., peculiar small-leaved *Cladophlebis* forms, representatives of the genus *Kchonomakidium*, and *Lepidopteris arctica* Mogutch. According to Mogucheva (1989), the Keshin taphofloras characterize in general the typical lepidophytic vegetation of coastal-marine plains of Siberia. The Early Triassic age of the taphofloras is defined based on coexisting ammonoids (Table 1).

The Middle–Late Triassic assemblages fossil plants from the Anokhino and Chelyabinsk sections of the eastern Urals are most comprehensively studied. These are the reference continental sections for both the eastern Urals and West Siberia. The recent taxonomic revision of taphofloras from the eastern Urals (*Novoe...*, 1980; Kirichkova, 1990a, 1990b) revealed their succession characterizing evolutionary stages of the Triassic flora, and corresponding flora-bearing horizons and beds were distinguished in sedimentary sequences (Kirichkova, 1993). In addition, the evolutionary stages of the Triassic flora in the eastern Urals and West Europe were correlated (Dobruskina, 1982; Kirichkova, 1990b).

Taphofloras of pteridosperm stage of Triassic flora evolution in the eastern Urals, which corresponds to the *Scytophyllum* Flora of West Europe (Dobruskina, 1982), are characteristic of the Kamyshin Horizon (Table 3). They are known from the upper Bichura Subformation and the Anokhino Formation of the Anokhino graben. Their dominants are seed ferns *Lepidopteris, Rhaphidopteris, Scytophyllum*, and others (Kirichkova, 1990a). The taphofloras are determined as reliably corresponding in age to the Middle–early Late Triassic interval (Table 3). Taphofloras from upper beds of the Kul'dima Formation, which contain abundant remains of Equisetopsida and seed ferns (*Lepidopteris, Rhaphidopteris, Scytophyllum, Peltaspermum*) in association with less abundant small-leaved *Cladophlebis*, are of the same evolutionary level. In West Siberia, fossil plants are known from the Varenga-Yakha and Vityutino formations penetrated by the borehole TSB-6 (Kirichkova *et al.*, 2000). Their assemblage of low diversity consists of prevailing Equisetopsida (*Neocalamites, Paracalamites, Equisetites*) and less frequent *Cladophlebis*. Similarly diverse Equisetopsida associated with rare *Cladophlebis* remains are characteristic also of the Kul'dima taphofloras in the eastern Taimyr and of the Baturino taphofloras from the lower Kalachevo Subformation (an upper part of the Kamyshin Horizon) of the eastern Urals. In spite of the higher taxonomic diversity (Kirichkova, 1990b, 1993; Mogucheva, 1982, 1984), the Kul'dima and Baturino taphofloras are probably correlative with the Varenga-Yakha and Vityutino taphofloras of West Siberia (Table 3).

The pteridosperm assemblages of East Uralian fossil plants are succeeded by taphofloras composed of horsetail, fern, and ginkgo remains characteristic of the Trans-Uralian Horizon (Kirichkova, 1990b, 1993) and correlative with the *Lepidopteris* Flora of Europe (Dobruskina, 1982). These taphofloras greatly differ from the preceding ones, because they predominantly consist of mesophytes, e.g., of *Cladophlebis* and associated rare representatives of *Clathropteris, Raphaelia*, diverse Ginkgoales, *Podozamites*, and earliest Pinaceae. Having low content of seed ferns, they also show the presence of the earliest Czekanowskiales.

Taphofloras of the Trans-Uralian Horizon are likely correlative with those detected in upper beds of the Nemtsov Formation in the Cape Tsvetkov (Tables 2; 3). Taxa prevailing in the Nemtsov taphoflora are *Cla-*

Table 3. Correlation of phytostratigraphic complexes from the Triassic reference sections of the Eastern Urals, West and Northern East Siberia

Series	Stage	Eastern Urals (Tuzhikova, 1973, 1985; Kirichkova, 1993): Phytohorizon	Floral stage	Phytostratigraphic assemblage	Palynological assemblage	West Siberia: borehole Nikol'skaya-1 (Klimko, 1986)	TSB-6 (Kirichkova *et al.*, 1999)	Northern East Siberia: Fossil plant assemblages (Moguchevа, 1982, 1984)	Palynological assemblage	Boreal zonation (Zakharov *et al.*, 1997; Konstantinov and Sobolev, 1999)
						Palynological assemblage				
J_1	Hettangian–Sinemurian	Trans-Urals	Horsetail–fern–ginkgo	Korkino		J_1	Beregovaya			
T_3	Rhaetian			Kozyrevskii						*T. efimovae*
										M. ochotica
										E. scitiformis
	Norian			Budanash				*Neocalamites, Cladophlebis*	Upper Nemtsov	*O. ussuriensis*
										P. verchojanicum
										S. kinasovi
	Carnian			Baturino			Vityutino		Lower Nemtsov	7 6 5 4 3 2 1*
T_2	Ladinian	Kamyshin	Pteridosp erms	Anokhino	Upper Anokhino	IV	Varenga-Yakha	*Neocalamites, Scytophyllum, Raphidopteris, Cladophlebis*	Kul'dima	Beds with *Discophyllites*
										N. lindstroemi
										N. mcconnelli
										N. maclearni
										J. krugi
					?	?				*T. neraensis*
										T. constantis
										E. oleshkoi
	Anisian				Lower Anokhino				Morzho-vaya	*F. nevadanus*
										G. rotelliforme
					Upper Bichura	II	Khadyr-Yakha			*A. kharaulakhensis*
										Cz. decipiens
										L. caurus
										G. taimyrensis
T_1	Olenekian				Lower Bichura	Ib		*Tomiostrobus, Pleuromeia, Lepidopteris arctica*	Ystanakh	*O. spiniplicatus*
										P. grambergi
										N. contrarium
										B. euomphala
										A. tardus
										L. kolymensis
										H. hedenstroemi
	Induan					Ia			Keshin	

* Carnian zones see in Table 2.

dophlebis and *Podozamites*, which associate with rare pteridosperms of the *Maria* type (Moguchevа, 1982, 1984). The assemblage is different from the Kul'dima taphoflora but similar to the Bulanash assemblage of the Trans-Uralian Horizon of the eastern Urals.

Taphofloras resembling the Nemtsov or Bulanash assemblages and fossil plants of the later Triassic are unknown in West Siberia. The Late Triassic through Early Jurassic sedimentation continued in the eastern Urals only. The Kozyrevskii and Korkino formations of

this age are characterized by corresponding phytostratigraphic assemblages, which significantly differ in taxonomic composition from assemblages typical of underlying deposits (Kirichkova, 1993).

CONCLUSION

The comprehensive analysis of paleobotanical data characterizing marine, coastal-marine, continental, and volcanogenic–sedimentary Triassic sequences of the eastern Taimyr, West Siberia (the Anabar–Olenek region, Tyumen' superdeep borehole 6 and deep borehole Nikol'skaya-1), and the eastern Urals (the Chelyabinsk and Anokhino grabens) enabled the interregional correlation of different rock facies. In addition, it is necessary to note the following:

(1) The correlative miospore taxa of terrestrial plants are used to establish taxonomic similarity between palynological assemblages from marine ammonoid-bearing deposits and continental strata. This allowed the precise dating of spore–pollen assemblages and relevant continental Triassic subdivisions of West Siberia and the eastern Urals. The dating results for the Bichura, Anokhino and Kalachevo formations of the eastern Urals are especially important, because their stratigraphic intervals were ambiguously interpreted before as ranging from the Late Permian through the Late Triassic.

(2) The palynological assemblages most persistent in taxonomic composition throughout the study regions are distinguished. These are the Ystanakh and analogous assemblages of the Olenekian age and the Kul'dima and analogous assemblages of the Ladinian–Carnian age. Their age levels can be used as datums for the interregional Triassic correlations in Siberia.

(3) Relationships between the Tura, Tampei and Krasnosel'kup groups of volcanic rocks and volcanogenic – sedimentary deposits are established for the first time.

(4) The gap in sedimentation between the Krasnosel'kup and Tampei groups is determined. The gap ranges from the middle Carnian (the borehole Nikol'skaya-1) or middle Norian (the TSB-6) to the earliest Jurassic in West Siberia and from the middle Norian to the earliest Jurassic in the northern East Siberia. The complete Triassic section of the eastern Urals is characterized throughout by the taphofloras and palynological assemblages that succeeded each other within the interval from the Induan Stage to the Early Jurassic.

(5) Data on spore–pollen assemblages and taphofloras confined to the same stratigraphic levels of the Triassic reference sections were analyzed for the first time. As a result, the floral assemblages from the continental deposits are now reliably dated. The Triassic taphofloras of the northern East and West Siberia are correlated with those of the eastern Urals.

Reviewers V.A. Zakharov and A.A. Shevyrev

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Horizons of Carbonaceous Rocks in Triassic and Lower Jurassic Cherty Deposits of the Dal'negorsk Reference Section (Primor'e)

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Abstract—Three horizons of phthanites and black carbonaceous mudstones are distinguished in the key section of Triassic and Jurassic cherty deposits of the Gorbusha Sequence near the Settlement of Dal'negorsk (Sikhote Alin). The first horizon in the lower part of the section is pre-Olenekian, probably Induan in age, related in origin to events of the Paleozoic–Mesozoic boundary time. The second horizon of local distribution is dated back to the early Anisian. Its deposition was likely associated with local events. The third horizon in the lower Toarcian beds can be interpreted, with a high probability, as a record of the early Toarcian anoxic event.

Key words: Triassic, Jurassic, phthanites, anoxia, cherty deposits, radiolarians, Sikhote Alin, Japan.

In old cherty deposits, a considerable attention has been recently focused on different horizons with a high content of organic matter (OM) and pyrite. Such horizons are usually interpreted as sediments deposited in anoxic environments. They are confined to certain stratigraphic intervals often characterized by notable faunal changes and are of wide distribution ranges in some cases. Horizons of this kind are known in Triassic and Lower Jurassic deposits of Japan (Hori, 1993; Ishiga *et al.*, 1996; Kakuwa, 1996) and in the Permian–Triassic boundary deposits of Nevada (Blome and Reed, 1995) and China (Kuwahara *et al.*, 1997). It should be pointed out that phthanites and other carbonaceous rocks are not as frequent in Mesozoic deposits of the Pacific belt as, for instance, in Lower and Middle Paleozoic deposits of Asia. Nevertheless, they are easily detectable and represent characteristic reference beds in some sections.

In this work, we consider carbonaceous horizons of the Dal'negorsk reference section of Primor'e, Triassic stratigraphy of which is studied in detail (Bragin, 1991). In addition to Triassic, the Lower Jurassic deposits of this kind have also been studied in the same section (Bragin, 1993; Kemkin *et al.*, 1997). Carbonaceous mudstones and phthanites were distinguished in this region by Volokhin *et al.* (1990) who believed that Triassic cherty deposits accumulated near a peneplanated land. It must be emphasized that even if this interpretation is correct, it does not account for the confinement of phthanites to certain stratigraphic intervals and for their absence in others.

The section parts described below and enclosing phthanites and carbonaceous mudstones were studied in 1997. These are the lowermost Lower Triassic, terminal Upper Triassic–lower Anisian, and Lower Jurassic intervals. All the described deposits are exposed along the right bank of Rudnaya River, where they belong to the second tectonic sheet of the Gorbusha nappe (Fig. 1).

LOWER TRIASSIC

Prevailing among Lower Triassic deposits of the Dal'negorsk section are cherty mudstones, whereas spongolite and radiolarian chert interlayers among them are of minor importance. Carbonaceous deposits are confined to the lower part of the section which is composed of the following units (Figs. 1, 2):

Unit 1(T_1i ?): black carbonaceous mudstone, intensely foliated, with disseminated pyrite inclusions and thin (2–3 cm) boudins of gray cherty mudstone in the upper part of the unit. The apparent thickness is 2.8–3 m.

Unit 2 (T_1ol_1): cherty mudstone, light blue–gray on a fresh surface and rusty–brown–black on the weathered one; the rock is massive, intensely foliated, with abundant disseminated pyrite inclusions, intercalated with few interlayers (1–2 cm) of black foliated carbonaceous mudstone and light gray spongolite. The thickness is 5 m.

Unit 3 (T_1ol_1): gray to light gray (dark gray on a weathered surface) cherty mudstone; the rock is platy, foliated in places, with frequent thin (1 cm) interlayers of light gray and bluish–gray glassy spongolite. The early Olenekian conodonts *Neospathodus pakistanensis* Sweet and *N. waageni* Sweet are found. The thickness is 5 m.

This interval of carbonaceous rocks is the most intriguing and, at the same time, most problematic in

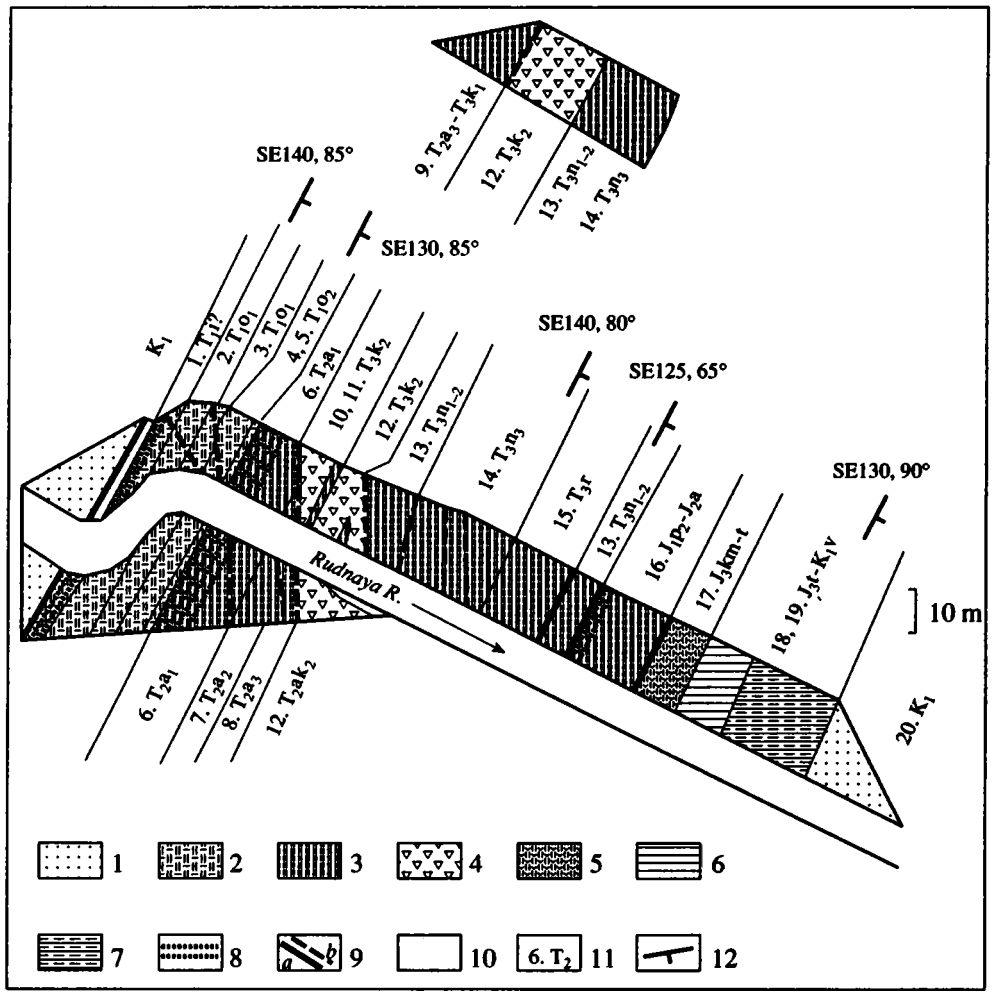

Fig. 1. Schematic structure of the Dal'negorsk reference section of Triassic and Jurassic cherty deposits: (1) sandstone; (2) cherty mudstone; (3) cherts; (4) basic volcanics; (5) cherty tuffite; (6) mudstone; (7) siltstone; (8) phthanite and black mudstone horizons; (9) thrust (*a*) and normal or strike-slip (*b*) faults; (10) dikes of intermediate volcanics; (11) unit number and age; (12) strike and dip of beds.

the Dal'negorsk section. According to position in the section, it is correlative with analogous deposits in many regions of Japan, where they are similar in lithology and also underlie beds with the early Olenekian fauna (Matsuoka *et al.*, 1994; Ishiga *et al.*, 1996; Kakuwa, 1996). Presence of carbonaceous horizons in Lower Triassic deep-sea sediments of Japan is regarded as indication of planetary anoxia at the Paleozoic–Mesozoic boundary time (Isozaki, 1997). A large-scale extinction of radiolarians (Bragin, 1991) and almost complete disappearance of biogenic cherty rocks widespread in the terminal Permian occurred in the initial Olenekian, beginning since the Permian–Triassic boundary time.

The age of Unit 1 cannot be established accurately enough, since it is free of paleontological remains. Moreover, the overlying Unit 2 yielded only few conodont remains of poor preservation and inappropriate for the reliable dating. Hence, we can thus concede the pre-Olenekian, most likely Induan age of Unit 1, assuming, though with reservations, the confinement of carbonaceous shales to the boundary between the Permian and Triassic. Volokhin *et al.* (1990) attributed units 1 and 2 to the lower Anisian justifying this by their lithologic similarity with the dated lower Anisian beds exposed downstream along the Rudnaya River (Unit 6 in the present description). The similarity is only visual however. The detailed study revealed no radiolarian cherts in units 1 and 2 in contrast to their mass abundance in Unit 6 (see below).

Black mudstones of Unit 1 are inappropriate for sedimentological analysis because of intense schistosity and boudinage, which destroyed their original textures. These rocks are confined to the base of the second tectonic sheet of the Gorbusha nappe (Bragin, 1991), so they have experienced a strongest tectonic impact. A similar situation is characteristic of Japan, where tectonic faults are concentrated within the Lower Triassic

interval composed of mudstones (Matsuoka *et al.*, 1994). Accordingly, it is difficult to assess the true thickness of the lowermost Lower Triassic, which varies in Japan from 15–20 (Sugiyama, 1992; Kakuwa, 1996) to 0.8 m (Ishiga *et al.*, 1996). This thickness variation may have been resulted from tectonic iterations of rock sheets, the extent of which is impossible to establish because of biostratigraphic data deficiency.

Nevertheless, some peculiar features of carbonaceous rocks in this interval of the Dal'negorsk section should be noted. Its lower part is completely composed of black mudstones, which are intercalated with interlayers of gray cherty mudstone in the upper part, and transition from Unit 1 to Unit 2 is gradual. Thin interlayers of black carbonaceous mudstone also appear upward in the section, in the upper portion of Unit 2. Features of this sort are common for such horizons, which often look like the alternation of carbonaceous and other rocks and have gradual lower and upper boundaries.

Red cherty mudstones with interlayers of radiolarian cherts (Unit 4, upper Olenekian, the thickness is 6.5 m) occur in the overlying section part that is free of carbonaceous intercalations. The latter appear again only near the roof of the Lower Triassic deposits and exemplify the second level of carbonaceous sedimentation in the Dal'negorsk section.

UPPERMOST UPPER OLENEKIAN–LOWER ANISIAN

In this interval of the Dal'negorsk section, carbonaceous rocks occur not as a member, but as few thin strata enclosed into monotonously alternating beds of cherty mudstone and radiolarian cherts. The structure of the section is as follows (Figs. 1, 2):

Unit 5 (T_1ol_2): gray–green to greenish brown platy and laminated cherty mudstones with rare thin interlayers of light bluish to gray cherts in the lower and middle parts of the unit, and with intercalations of black carbonaceous mudstone near the unit top. Fossils of the unit are radiolarians *Cryptostephanidium japonicum* (Nakaseko et Nishimura), *Hozmadia ozawai* Sugiyama, *Parasepsagon* sp. cf. *P. longidentatum* (Kozur et Mostler), *Parentactinia nakatsugawaensis* Sugiyama, *Paroertlispongus diacanthus* (Sugiyama), *P.* sp. A, *P.* sp., *"Paurinellinae," Pseudostylosphaera kozuri* Sugiyama, *P. fragilis* (Bragin), *Spongostephanidium longispinosum* Sashida and conodonts *Neospathodus homeri* (Bender) and *N. spathi* Sweet of the late Olenekian age. The thickness is 2 m.

Unit 6 (T_2a_1): gray and dark gray cherts, locally with light bluish tint; the rocks black and rusty–brown on the weathered surface are massive to medium-platy (5 cm), rich in sulfides, enclosing few (5–6) thin (1–10 cm) interlayers of black carbonaceous mudstone with abundant sulfide inclusions. Interlayers of gray to greenish gray cherty mudstone are abundant in the lower part of

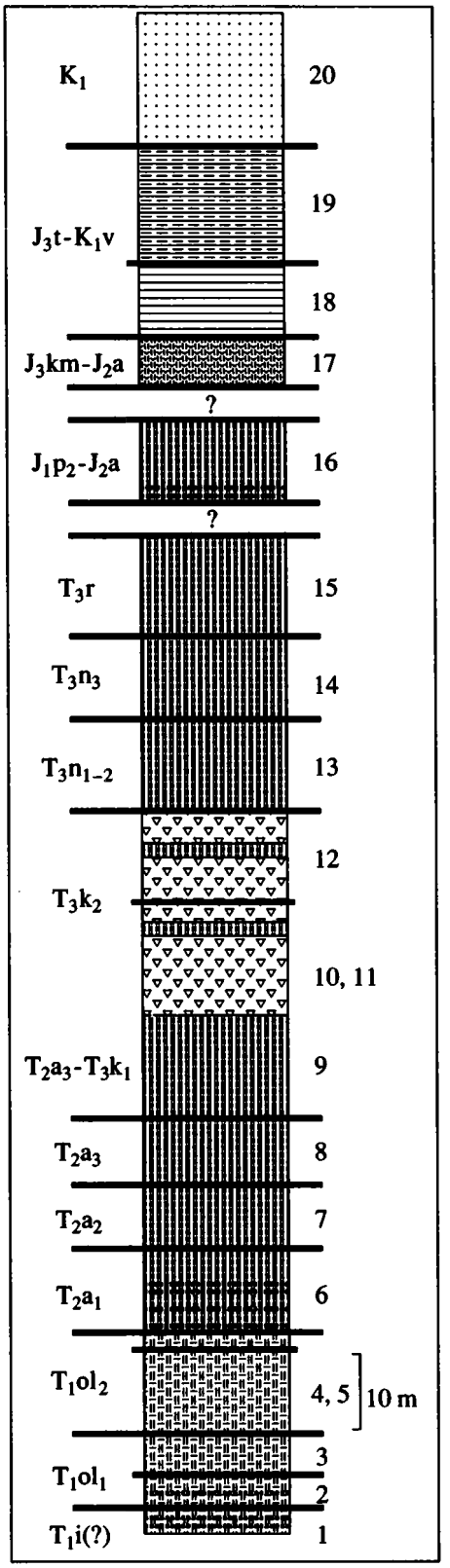

Fig. 2. Lithostratigraphic column of the Dal'negorsk reference section and position of carbonaceous rock horizons (age indices on the left and unit numbers on the right; other symbols as in Fig. 1).

the unit. Radiolarians characterizing the unit are *Celluronta donax* Sugiyama, *C.* (?) sp., *Cryptostephanidium japonicum* (Nakaseko et Nishimura), *Eptingium nakasekoi* Kozur et Mostler, *Hozmadia ozawai* Sugiyama, *H. gifuensis* Sugiyama, *Parentactinia nakatsugawaensis* Sugiyama, *Parasepsagon* sp. aff. *P. longidentatum* (Kozur et Mostler), *Parentactinia nakatsugawaensis* Sugiyama, *Paroertlispongus diacanthus* (Sugiyama), *P.* sp. B, *Paurinellinae* sp. A, sp. B, sp. C, *Pseudostylosphaera* sp. A (Sugiyama), *P. fragilis* (Bragin), *Sepsagon* sp., *Spongostephanidium longispinosum* Sashida, *Tiborella* sp., and *Triassocampe* (?) sp. They associate with conodonts *Neospathodus timorensis* (Nogami), *N. homeri* (Bender), and *Neogondolella regale* Mosher (two last forms are from the lower part of the unit). The above assemblages of microfauna are typical of the early Anisian. The thickness is 13 m.

Unit 7 (T_2a_2): rhythmically alternating layers of light bluish gray cherts and greenish gray cherty mudstones; the layers of uniform thickness (7–8 cm) yield the middle Anisian radiolarians and conodonts. The apparent thickness is 4 m.

Thin layers of black mudstones are evenly distributed through the whole interval of the lower Anisian. They are more plastic than cherty mudstones and cherts enclosing them, and produce swells and injections along fissures in the places, where these horizons are displaced by strike-slip or other minor faults. Carbonaceous horizons have sharp and distinct contacts with enclosing rocks. At the same time, sulfide impregnation is almost equally widespread in all rock types of Unit 6, being substantially reduced in Unit 7. Anoxic or close to that environments of sedimentation were likely characteristic of the whole interval from the upper part of Unit 6 to the top of Unit 7, which corresponds in range to the terminal upper Olenekian and the whole lower Anisian.

It should be pointed out that this stratigraphic interval of the Dal'negorsk section is distinct because of an increasing diversity of radiolarians. Several new their groups appears here: multicyrtoid nassellarians of genera *Triassocampe* and *Celluronta*, highly organized *Eptingium* forms, and others. This phenomenon is connected with a rapid growth of silica productivity: the accumulation cherts constitute about 5–10% of the total thickness in Unit 5 and about 50% in Unit 6. Radiolarian cherts also dominate in the overlying middle–upper Anisian deposits.

The high rate of chert accumulation and increase in the taxonomic diversity of radiolarians coincide in time and seem to be interrelated. Similar phenomena are recorded in other sections of lower Anisian deposits in the Khabarovsk region (Bragin, 1992) and in central regions of Japan (Sugiyama, 1992; 1997; Matsuoka *et al.*, 1994; Kamata and Kajiwara, 1996), but all sections in these regions differ however from the Dal'negorsk section, as they lack carbonaceous rocks. Outside the Dal'negorsk area, the latter are known only in the lower Anisian sections of eastern Primor'e: near the Settlement of Sadovyi (15 km southeast of Dal'negorsk) and in the upper reaches of the Vysokogorskaya River (20–25 km west of Dal'negorsk).

It should be noted that some well-studied and widespread levels that mark anoxic events, for instance, the Cenomanian–Turonian or early Toarcian levels, characterize the growth of chert accumulation and the subsequent increase in taxonomic diversity of radiolarians (Hori, 1993; O'Dogherty, 1994). These records are regarded as related in origin to anoxic events. Carbonaceous rocks present in the lower Anisian interval of the Dal'negorsk section do not occur however in concurrent intervals in the Khabarovsk region and Japan. Consequently, the early Anisian anoxia could be of a local significance in eastern Primor'e. If this is the case, the local anoxia and the increased diversity of radiolarians at the beginning of the Anisian are not in the cause-and-effect relations but simply coincide in time.

The overlying deposits are represented by the middle Anisian–lower Carnian gray radiolarian cherts and next by the upper Carnian pillow basalts, hyaloclastites, and jaspers, which underlie the Norian to Rhaetian gray radiolarites (Bragin, 1991). Anoxic events are not recorded within this interval of the Triassic in the Dal'negorsk section, though the Lower Jurassic part of the latter encloses a characteristic horizon of carbonaceous mudstone and phthanite.

LOWER JURASSIC

The upper part of the Dal'negorsk section (the Upper Triassic and Jurassic intervals) is dislocated more intensely as compared to its lower parts. Some stratigraphic intervals are doubled here, whereas some others (the Hettangian–Sinemurian, the greater part of the Pliensbachian, and the Bajocian–Bathonian) are missing (Bragin, 1991, 1993; Kemkin *et al.*, 1997). The Lower Jurassic deposits exposed along the Rudnaya River banks, have tectonic contacts with both the underlying Upper Triassic cherts and the overlying Upper Jurassic cherty tuffites. Their section includes the following units (Figs. 1, 2):

Unit 15 (T_3r_1): gray, in places dark gray to greenish gray thin-platy cherts intercalated with light gray massive silicified cherts and with rare interlayers of brownish gray cherty mudstone. Radiolarians found here are *Ayrtonius elisabethae* Sugiyama, *Bipedis acrostylus* Bragin, *Canoptum rhaeticum* Kozur et Mostler, *Dreyericyrtium ithacanthum* Sugiyama, *Livarella densiporata* Kozur et Mostler, *L. longa* Yoshida, *Mesosaturnalis inaeguatus* (Bragin), *Praemesosaturnalis gracilis* (Kozur et Mostler), *P. heilongjiangensis* Yang et Mizutani, *P. hexaspinosus* (Bragin), *P. multidentatus* (Kozur et Mostler), *P. aciferus* (Bragin), *P. diminutus* (Bragin), *Pseudoheliodiscus pseudosymmetricus* (Kozur et Mostler), *Risella tledoensis* Carter, and *Toro-*

saturnalis orientalis Bragin. They associate with conodonts *Misikella posthernsteini* Kozur et Mock. The thickness is 8 m.

The brecciated zone with section fragments (lower and middle Norian, Pliensbachian) doubled parallel to bedding planes (Bragin, 1993); massive to slightly platy cherts are here gray to light gray in color, intensely silicified and brecciated. The zone width is 6 m.

Unit 16: lilac–gray, in places greenish gray to reddish gray–brown thin-platy banded cherts displaying wavy lamination and enclosing fine coaly detritus; at the level of 0.5 m above the base, the unit encloses a horizon (0.5 m) of black carbonaceous schistose mudstone with interlayers (2–3, some over 5 cm thick) of black phthanite impregnated with pyrite. The lower contact of the unit is uneven and very sharp. This seems to be the former intrastratal shear in poorly lithified sediments. Pliensbachian radiolarians found below phthanites are *Parahsuum longiconicum* Sashida, *P. simplum* Yao, *P. kanyoense* Sashida, *Trillus* sp. aff. *T. elkhornensis* Pessagno et Blome. The lower Toarcian radiolarians *Parvicingula gigantocornis* Kishida et Hisada, *P. nanoconica* Hori et Otsuka, *Parahsuum transiens* Hori et Otsuka, and *Hsuum medium* (Takemura) characterize the top of phthanite interlayer and higher interval up to the level of 4.5-m above the unit base. Phthanites and cherts directly overlying them also yielded redeposited remains of Triassic conodonts (Bragin, 1991, 1993). The middle Toarcian–Aalenian radiolarians *Crubus wilsonensis* Carter and others are characteristic of higher levels (Bragin, 1993; Kemkin *et al.*, 1997). The thickness is 12 m. A fault marked by the rusty–brown brecciation zone (up to 0.5 m) truncates the unit along the strike.

Unit 17: gray–green and light bluish green massive to thick-platy cherts, locally tuffaceous and clayey (tuffaceous cherty mudstone), bearing abundant and diverse Late Jurassic radiolarians (Bragin, 1993; Kemkin *et al.*, 1997). The thickness is 6.5 m.

Volokhin *et al.* (1990) attributed Unit 16 to the Middle Triassic based on redeposited conodonts and visual lithological similarity. Their inference is disproved by found radiolarians.

Hence, only a thin horizon of black mudstones and phthanites is detected in the lower Toarcian interval of the Dal'negorsk section. A similar horizon is known in the lower Toarcian interval of some cherty sequences in Japan (Matsuda and Isozaki, 1982; Isozaki and Matsuda, 1985; Hori and Matsuda, 1990; Hori, 1993; Isozaki and Maruyama, 1992; Ishiga, 1993; Matsuoka *et al.*, 1994). Many features suggest identical origin of the horizon in the Sikhote Alin and Japan.

In Japanese sections, the early Toarcian anoxic event is recorded by deposition of a black chert bed with pyrite, the thickness of which does not exceed 0.5 m. The bed is enclosed in platy cherts everywhere, being overlain by a bed of Mn-rich jasper in the Katsuyama section, Inuyama Prefecture, central Japan (Hori, 1993). Its level corresponds to the upper part of Subzone IV of the radiolarian *Parahsuum simplum* Zone of the early Toarcian. In some sections, a hiatus may predate this horizon. For instance, the lower Toarcian phthanites rest on the lower Pliensbachian deposits in the Kurusu section (Inuyama) and even on Upper Triassic deposits in the Kamiaso section (Matsuda and Isozaki, 1982). Redeposited remains of Triassic conodonts found somewhere in phthanites and overlying cherts undoubtedly imply an intense erosion of Triassic deposits during the hiatus time.

It is very important that the lower Toarcian phthanite horizon of Japan was deposited immediately before a substantial renovation in radiolarian assemblages. Many new radiolarian taxa appear simultaneously, or nearly simultaneously, in all sections directly above the phthanite layer. These are genera *Parvicingula* s.s. (*P. gigantocornis, P. nanoconica*) and *Archaeodictyomitra*, representatives of the genus *Hsuum* (*H. altile* Hori et Otsuka, *H. medium*, and others), and diversity of their species grows noticeably. In contrast, radiolarians from layers underlying the phthanite horizon look stunted that is evident, for instance, from variability of the shell length of multicyrtoid nassellarians. Hori (1993) who analyzed this parameter in a great sample of transit nassellarian species found out that the average length of their shells decreases by the end of the late Pliensbachian to rise considerably in the early Toarcian immediately after the anoxic event.

The considered data show that the lower Toarcian phthanites of the Dal'negorsk section are very similar to coeval rocks of Japan. Consequently, the corresponding anoxic event seems to be traceable in Japan and Sikhote Alin. Moreover, the early Toarcian anoxic event is also known in other regions, for instance, in European sections of pelagic carbonates (Jenkyns, 1988). Some researchers suggested a global nature of this phenomenon (Hori, 1993; Ishiga, 1993; Matsuoka *et al.*, 1994). Finally, the taxonomic diversity outburst is established among Toarcian radiolarians from other regions, for instance, from North America (Carter *et al.*, 1988).

CONCLUSION

In the Dal'negorsk reference section of Triassic and Jurassic cherty deposits, there are three levels with black mudstones and phthanites, which are enriched in carbon. These are the presumably Induan, terminal upper Olenekian–lower Anisian, and lower Toarcian levels. We believe that they are records of local and wider significance. Sedimentation under reduced (anoxic) conditions has not been characteristic of the Dal'negorsk and other Mesozoic cherty sections of the Pacific belt, and corresponding events are recorded at separate levels only. These levels with phthanites and black mudstones most likely reflect sharp changes in sedimentation environments.

A horizon of presumably Induan age has analogs in many sections of Japan and may be indicative of an anoxic event at the Permian–Triassic boundary time. This cannot be stated with a full confidence however, as paleontological indicators of the horizon age are unknown so far. Another lower Anisian horizon is established in the Dal'negorsk region only, and a local event could be responsible for its deposition. The lower Toarcian phthanites of the Dal'negorsk region are correlative with coeval deposits in Japan, and their origin was likely associated with the well-known anoxia of global scale that took place at the beginning of the Toarcian.

All carbonaceous horizons of the Dal'negorsk section coincide with important events in evolution of Mesozoic radiolarians, though this is not necessarily an indication of interrelationships between two phenomena under consideration. The absence of radiolarians in layers inferred to be Induan is related to their mass extinction at the Permian–Triassic boundary time, when it could be caused by many reasons except for anoxia. The increased diversity of radiolarians at the beginning of the Anisian may have no relation to the appearance of anoxic rocks in this interval of the Dal'negorsk section, since rocks of this kind have not been found in remote sections (Japan, the Khabarovsk region), where radiolarians show distribution patterns similar to those of the Dal'negorsk section. A renewal of radiolarian assemblages in the early Toarcian was likely related to an anoxia, since corresponding changes in taxonomic composition of radiolarians and interrelated appearance of phthanites are well traceable in many sections. To explain these interrelations also established in other stratigraphic intervals, for instance, in the Cenomanian–Turonian (O'Dogherty, 1994), we suggest the following mechanism. Anoxic conditions intensely depress development of marine biota, many radiolarian taxa included. The extinct components of biota left some ecological niches free. Occupation of these niches after the anoxic event accelerated the biota diversification and led to appearance of a great variety of new taxons.

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Radiolarian Biostratigraphy of the Maastrichtian in the Eastern Tajik Depression

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Abstract—New data on the Maastrichtian stratigraphy in the eastern Tajik depression are discussed. Scarce remains of macrofauna and significant facies variability are main impediments to precise correlations between deposits of Afghanistan and Tajikistan. Coexisting ammonoids, larger foraminifers, and radiolarians enable age determination of the Maastrichtian limestone sequences in the eastern Tajik depression, where occurrence of the lower Maastrichtian sediments is confirmed. The early Maastrichtian age of the radiolarian *Hemicryptocapsa djalilovi* assemblage corresponding to the ammonoid *Nostoceras hyatti* Zone is substantiated. Based on changes in radiolarian assemblages, the identification of the upper Campanian–lower Maastrichtian boundary is proved to be possible in the east of the region, where ammonoids are missing. The lower-upper Maastrichtian boundary corresponds to the level, where the radiolarian *Hemicryptocapsa djalilovi* assemblage is replaced by larger foraminifers of the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage. The base of the Maastrichtian is displaced down in accord with the ammonoid and radiolarian records.

Key words: Upper Cretaceous, Maastrichtian, ammonoids, radiolarians, larger foraminifers.

The Maastrichtian and Campanian calcareous sediments in the eastern Tajik depression were considered until recently as bearing very scarce remains of macrofauna (Dzhalilov, 1971).

During subsequent investigations, different fossil groups, including ammonites, foraminifers, radiolarians, and others, were discovered in the studied sediments (Dzhalilov, 1988). Based on newly found remains of microfauna, biostratigraphic subdivision of both stages was refined. However, not all the problems were solved by the beginning of this work, and further investigation of reference sections turned out to be desirable. Most important among the latter (see the figure) were the Akdzhar (Aruktau Ridge), Bulakdasht (junction point of the Sarsaryak and Tabakchi ridges), Bulgari (Vakhsh Ridge), and the Verkhnii Khirmanzhou (Khozretishi Ridge) sections.

Works by Ashurov *et al.* (1987) and by Khakimov (1990, 1998) were significant in this respect, especially the latter devoted to ammonoid assemblages.

The analyzed sections were selected because of their completeness and representative composition of radiolarian assemblages. They also offer a possibility of the detailed correlation between the radiolarian, ammonoid, and foraminiferal biostratigraphic units. Radiolarians were mainly studied in smear-slides.

The species composition of radiolarian assemblages is presented in Table 1, and the layer-by-layer radiolarian record is depicted by description of sections presented below. Some of species were described earlier (*Atlas* ..., 1998, pp. 37–70).

The Bulakdasht section was studied at the junction point of the Sarsaryak and Tabakchi ridges. The following units are distinguished here (from the base upward).

Campanian (uppermost part)

Trachyscaphites pulcherimus Zone (upper part)

Gongylothorax tadjikistanensis Beds (upper part)

(1) Bluish gray, clayey, fine-detrital limestone with spheroidal parting; remains of *Micraster* sp., *Hoplitoplacenticeras vari* (Schluter), *H. bucharense* Iljin, and radiolarian assemblage with *Gongylothorax tadjikistanensis* (Table 1, column 2) occur near the base of the unit. The total thickness is 37.3 m.

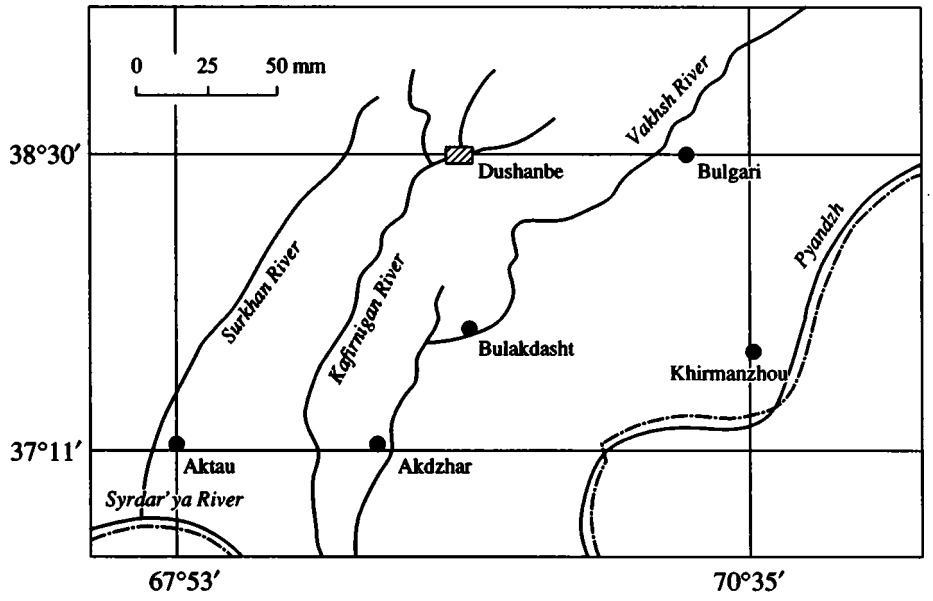
Maastrichtian

Nostoceras hyatti Zone

Hemicryptocapsa djalilovi beds

(2) Bluish gray, clayey, fine-detrital, lumpy limestone (12 m thick) bearing the radiolarian assemblage with *Hemicryptocapsa djalilovi* (Table 1, column 5; Plate I).

(3) Light gray, clayey, finely detrital, platy limestone, with fucoids near the top; the lower part of the bed yields remains of ammonites *Didymoceras schloenbachi* (Favre). Ammonites *Nostoceras hyatti* Stephenson, *Agerostrea falcata* (Mort.), and *Agerostrea* sp. in association with *Inoceramus* sp. are characteristic of the middle part, and the upper part yields *Inoceramus* sp. and *Nostoceras hyatti* Stephenson. Sediments contain the radiolarian assemblage with *Hemicrypto-*



Localities of the studied sections.

capsa djalilovi (Table 1, column 5; Plate I). The total thickness is 13.0 m.

(4) Unexposed interval 9 m thick.

(5) Gray, clayey, oyster limestone (10.3 m thick); glauconite grains, phosphorite concretions, fucoids, and internal molds of bivalve mollusks occur in the lower part of the bed. The *Hemicryptocapsa djalilovi* assemblage of the unit is considerably impoverished (Table 1, column 5). The total thickness of the lower Maastrichtian is 44.3 m.

Upper Maastrichtian

(6) Light gray dolomitized limestone (5 m thick) bearing glauconite grains in the uppermost part of the bed.

(7) Gray cavernous limestone 2 m thick, bearing small phosphorite grains.

(8) White farinaceous cavernous dolomite 2.2 m thick, showing gentle weathering forms.

(9) Gray cavernous limestone 1.8 m thick, bearing phosphorite grains.

(10) White farinaceous loose dolomite 2.5 m thick, showing traces of erosion.

(11) Gray cavernous limestone bearing phosphorite grains and a coquina lens (0.3 m) that is composed of broken valves of *Pycnodonte vesiculare* (Lam.); poorly preserved remains of larger foraminifers are detected in smear-slides. The unit yields scarce radiolarians *Orbiculiforma* cf. *volgensis* (Limp.), *O.* cf. *renillaeformis* (Campbell et Clark), *Sethocapsa* cf. *nobilis* Tan Sin Hok, *Theocampe* ex gr. *subtilum* Squinabol, *Amphipyndax* sp., and *Holocryptocapsa* sp. 1 (Table 1, column 8; Plate II). The total thickness is 2.3 m.

(12). Dolomitized limestone (1.6 m) bearing phosphorite and glauconite grains.

(13) Hard, light gray, dolomitized limestone with glauconite grains; the uppermost part of the bed (0.6 m) contains internal molds of bivalve mollusks. The total thickness is 10.0 m.

(14) Light gray, dolomitized, hard limestone 1.5 m thick.

(15) Light gray, farinaceous dolomite 2.4 m thick.

(16) Bioclastic limestone 2.1 m thick; the upper part is composed of rudist fragments (Radiolitidae).

(17) Yellowish gray, coarsely crystalline, in places fine-grained limestone (1.1 m thick) bearing small phosphorite grains. The total thickness of the upper Maastrichtian is 34.5 m.

The *Hemicryptocapsa djalilovi* assemblage is most representative in beds 2 and 3 of the Bulakdasht section. About one third of its species is unknown from underlying horizons. The assemblage mainly consists of the Eucyrtidiidae and Williriedellidae species. The following taxa known from the Maastrichtian of California (Pessagno, 1971; Campbell and Clark, 1944) are identified in the assemblage: *Phaseliforma* cf. *laxa* Pessagno, *Orbiculiforma* cf. *renillaeformis* (Campbell et. Clark), *Patulibracchium* ex gr. *taliaferroi* Pessagno, *P.* cf. *teslaensis* Pessagno, *Stichopilidium* ex gr. *teslaense* Campbell et Clark, *?Stichocapsa* cf. *livermorensis* (Campbell et Clark), *Diacanthocapsa* cf. *granti* (Campbell et Clark), and *D.* cf. *amphora* (Campbell et Clark). Pessagno (1976) included all these taxa into the Maastrichtian *Orbiculiforma renillaeformis* assemblage from the Californian coast of North America. *Patulibracchium taliaferroi* and *P. teslaense* are also known from the *Patulibracchium dickersoni* Subzone

Table 1. Distribution of radiolarians in the upper Campanian and Maastrichtian sediments of the eastern Tajik depression

Radiolarian species \ Distribution of radiolarians in sections	*Gongylothorax tadjikistanensis*			*Hemicryptocapsa djalilovi*			*Cenosphaera micropora–Holocryptocapsa* sp. 1			*Diacanthocapsa*		
Cenosphaera aff. *euganea* Squinabol	—											
Prunobrachium cf. *articulatum* (Lipman)	—	—	—									
P. cf. *crassum* (Lipman)		—										
Spongoacanthus cf. *horridus* Squinabol	—											
Amphibrachium cf. *mucronatum* Lipman	—											
Parvicuspis cf. *shastaensis* Pessagno	—	—										
Cenodiscus macroporus Gol'tman	—	—										
Spongodiscus cf. *orbis* Campbell et Cralk	—	—	—									
Alievium atypicum Gol'tman	—	—										
Sethodiscus priscus Gol'tman	—	—	—									
Euchitonia cf. *triradiata* Lipman		—										
Rhopalastrum cf. *dalpiasi* Squinabol	—	—	—	—								
Patulibracchium cf. *californiensis* Pessagno	—											
Patulibracchium sp. B	—	—										
Dictyastrum sp.	—											
Crucella cf. *latum* (Lipman)	—											
Gongylothorax tadjikistanensis Gol'tman	—	—	—									
G. cf. *verbeeki* (Tan)	—											
Lithostrobus cf. *rostovzevi* Lipman	—											
Stichocapsa ex gr. *japonica* Yao	—											
Eucyrtis (cf. *Lithocampe fusiformis* Hinde)	—	—										
Spondocapsula ex gr. *palmerae* Pessagno	—											
S. cf. *samoraensis* Pessagno	—											
Spirocapsa cf. *holospiralis* (Rüst)	—	—	—									
Sethocapsa aff. *martini* Tan	—	—	—									
Stichomitra cf. *manifesta* Foreman	—											
Hemicryptocapsa sp. 1	—	—	—									
H. verrucata Gol'tman	—	—	—									
Becoma ex gr. *pidarfensis* Riedel et Sanfillipo	—											
Ectonocorys cf. *blanchae* (Camp. et Cl.)	—											
Diacanthocapsa cf. *galeata* Dumitrica	—	—										

Table 1. (Contd.)

Radiolarian species \ Distribution of radiolarians in sections	*Gongylothorax tadjikistanensis*			*Hemicryptocapsa djalilovi*			*Cenosphaera microporа–Holocryptocapsa* sp. 1			*Diacanthocapsa*		
D. cf. *umbilicata* Dumitrica		—										
Holocryptocapsa cf. *fallax* Tan	—	—										
Zhamoidellum demissicium Gol'tman	—	—			—							
Tricolocapsa cf. *triangularis* Tan	—											
Theocapsa sp.	—	—										
Zanola sp.	—			—								
Amphibrachium sibiricum Gorbovetz	—	—	—	—	—	—						
A. spongiosum Lipman	—	—	—	—	—	—						
A. cf. *issele* Squinabol	—			—								
Phaseliforma cf. *carinata* Pessagno	—	—		—	—							
Ph. foremanae Gol'tman	—	—		—	—							
Cavaspongia cf. *viminea* Gol'tman	—	—	—	—								
Rhopalastrum cf. *retusum* Rüst	—		—	—								
Patulibracchium cf. *lawsoni* Pessagno	—			—								
P. ex gr. *delvallensis* Pessagno	—	—	—	—	—	—						
Patulibracchium sp. A	—			—								
Foremanella cf. *diamphidia* (Foreman)	—			—								
Crucella crux (Lipman)	—	—	—	—	—							
C. cf. *aster* (Lipman)	—					—						
Clathrocyclas cf. *tintinabulum* (Grig.)	—		—	—	—							
Amphipyndax stocki (Campbell et Clark) var. B	—				—							
Novixitus sp. B	—	—		—								
Excentropylomma cf. *cenomana* Dumitrica	—											
Crytocapsa singularis Gol'tman	—			—								
Hemicryptocapsa cf. *simplex* Dumitrica	—				—							
Stylocapsa cf. *hastellata* Tan	—			—	—	—						
Holocryptocanium cf. *japonicum* Nakaseko et Nishimura	—	—	—	—	—	—						
Homeoarchicorys cf. *eiformigum* Empson-Morin	—	—		—	—	—						
Cryptamphorella cf. *sphaerica* (White)	—	—	—			—			—			
C. cf. *challengeri* Schaaf	—	—	—		—							
Zhamoidellum parvipora var. α (Tan)	—			—								

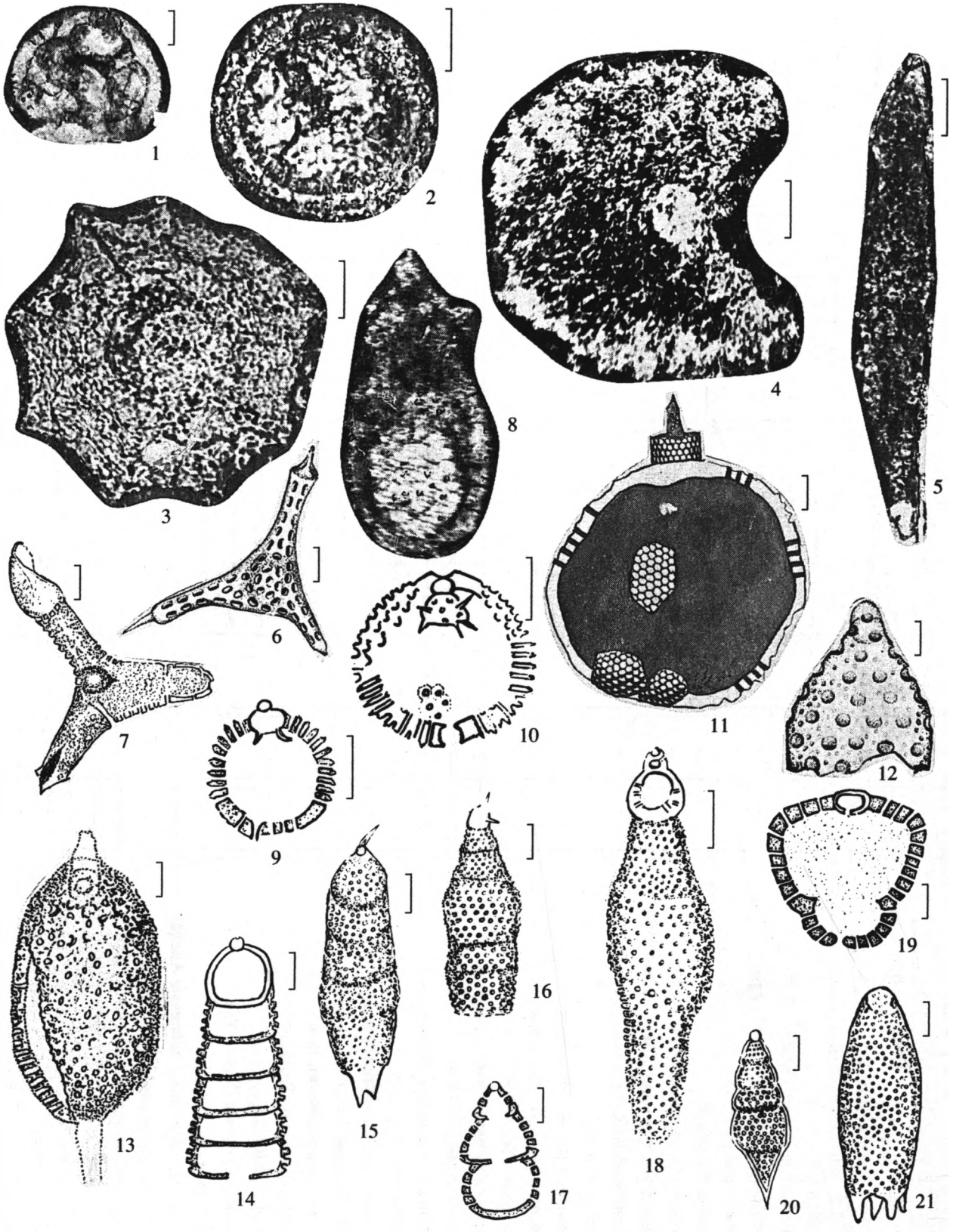
Table 1. (Contd.)

Radiolarian species \ Distribution of radiolarians in sections	*Gongylothorax tadjikistanensis*			*Hemicryptocapsa djalilovi*			*Cenosphaera micropora–Holocryptocapsa* sp. 1			*Diacanthocapsa*		
Stephoidea gen. et sp. ind.	—	—		—	—							
Congylothorax tadjikistanensis spongia Gol'tman	—			—		—	—	—	—		—	
Holocryptocanium sp. 1	—			—		—						
Dorysphaera cf. *armenica* Kasinzova				—		—			—			—
Ditrabs cf. *clavatum* (Rust)				—								
Hemicryptocapsa djalilovi Gol'tman				—		—		—				
Phaseliforma cf. *laxa* Pessagno				—								
Spongurus cf. *ocidentalis* Campbell et Clark				—		—						
Orbiculiforma cf. *sacramentoensis* Pessagno				—								
O. cf. *renikkaeformis* (Campbell et Clark)				—	—	—	—					
Porodiscus cf. *vulgaris* Lipman				—		—	—					
Patulibracchium ex gr. *taliaferroi* Pessagno				—								
P. cf. *teslaensis* Pessagno		—		—	—							
Foremanella cf. *hipposidericus* (Foreman)				—								
Dicolocapsa sp. 1				—	—	—						
Bullacapsula cf. *schirkentica* (Gol'tman)				—	—	—						
Gongylothorax cf. *cephalocrypta* (Tan)				—		—		—				
G. cf. *sifonofer* Dumitrica				—								
?*Lophophaena* cf. *polycyrtis* (Campbell et Clark)				—								
Calyptocoryphe cf. *cranaa* Foreman				—								
Gongylothorax cf. *prunum* Dumitrica				—	—	—						
Cryptocapsa tricyclia Rüst				—								
C. ex gr. *asymmetros* Foreman				—								
Diacanthocapsa cf. *granti* (Campbell et Clark)				—		—						
Carpocanium sp.				—								
Theocapsa sp.				—								
Theocapsa ex gr. *salillum* Foreman					—							
Theocapsa inflata (Squinabol)				—								
Cyrtocapsa cf. *houwi* Tan				—								
Acidnomelos ex gr. *laevis* Petrushevskaya					—							
Stichopilidium cf. *teslaense* Camp. et Clark					—							

Table 1. (Contd.)

Radiolarian species \ Distribution of radiolarians in sections	*Gongylothorax tadjikistanensis*			*Hemicryptocapsa djalilovi*			*Cenosphaera micropora–Holocryptocapsa* sp. 1			*Diacanthocapsa*		
Cornucapsula sp. 1					—							
Spongocapsula cf. *preampla* (Rüst)				—								
Stichomitra cf. *asymbatos* (Foreman)				—								
Theocampe cf. *elata* Tan				—								
T. ex gr. *subtilis* Squinabol				—			—					
Hemicryptocapsa ex gr. *pseudopilula* (Tan)				—								
?Stichocapsa cf. *livermorensis* (Campbell et Clark)				—								
Eucyrtis cf. *pantanelli* (Rüst)				—								
Xiphoteca sp.				—								
Myllocercion sp.				—								
Protostichocapsa sp.				—								
Eucyrtis micropora Squinabol				—								
Cenosphaera micropora Cayeux	—								—			—
Spongodiscus minima Gol'tman	—	—	—	—	—	—	—	—	—			—
Orbiculiforma cf. *volgensis* (Lipman)	—	—	—	—					—			
Holocryptocapsa sp. 1	—	—	—	—					—			
Squinabollum cf. *fossilis* (Squinabol)	—		—	—	—	—		—			—	
Spongodiscus maximus Lipman				—				—				
Dorysphaera longoacantha Gol'tman				—							—	—
Paronaella cf. *venadoensis* Pessagno				—				—				
Sethocapsa cf. *nobilis* Tan				—	—	—	—	—				—
Dictyocephalus cf. *cayeuxi* (Squinabol)				—	—	—	—	—				
Amphipyndax sp.				—	—			—	—			
Tetracapsa sp. (cf. *Stichocapsa haltaensis* Aliev)	—		—	—		—		—				—
Sethocapsa pomum Squinabol				—								—
Diacanthocapsa cf. *amphora* Campbell et Clark	—			—								—
D. ex gr. *ovoida* Dumitrica	—											
D. cf. *teren* (Foreman)				—		—						—
D. cf. *ancus* (Foreman)				—								—
Diploplegma bacciforma Tchedia												—

Note: Columns 2, 5, 8, 11—the Bulakdasht section; 3, 6, 9, 12—the Bulgari section; 4, 7, 10, 13—the Verkhnii Khirmanzhou section.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corresponding to the uppermost Campanian, but their occurrence in the Maastrichtian is also possible (Pessagno, 1971). *Stichomitra asymbatos* (Foreman), *Cryptocapsa asymmetros* (Foreman), *?Lophophaena polycyrtis* (Campbell et Clark), and *Calyptocoryphe cranaa* Foreman were described from the upper Maastrichtian of California (Foreman, 1968) and found in the Maastrichtian of the eastern (Leg 41, Site 369A) and southwestern (Leg 17) Atlantic Ocean (Foreman, 1977, 1978). *Clathrocyclas tintinabulum* (Grig.) is known from the Maastrichtian of the Urals and Transuralian areas (Grigor'eva, 1975). Kasinzova and Vishnevskaja (1988) considered it as an index species of the Maastrichtian in central Russia. *Tetracapsa inflata* (Squinabol), *Theocampe subtilis* Squinabol, *Eucyrtis micropora* Squinabol, and *Sethocapsa pomum* Squinabol are detected in Senonian deposits of Sicily. *Gongylothorax cephalocrypta* (Tan Sin Hok), *Cyrtocapsa houwi* Tan Sin Hok, *Hemicryptocapsa pseudopilula* (Tan Sin Hok), and *Sethocapsa nobilis* Tan Sin Hok represent Senonian taxa from Java, Indonesia. All the species mentioned above have not been encountered below the Maastrichtian sediments of the Tajik depression (Table 1).

The level separating the *Gongylothorax tadjikistanensis Hemicryptocapsa djalilovi* assemblages corresponds to the Campanian-Maastrichtian boundary. It marks the appearance of *Patulibracchium* ex gr. *taliaferroi, Orbiculiforma* cf. *sacramentoensis, Phaseliforma* cf. *laxa, ?Lophophaena* cf. *polycyrtis, Calyptocoryphe* cf. *cranaa, ?Stichocapsa* cf. *livermorensis*, and others. Abundant *Gongylothorax tadjikistanensis* var. *spongia* Gol'tman whose first occurrence is recorded somewhat lower also appears in the same interval together with the index species and *Holocryptocanium* sp. (Gol'tman, 1981, 1984). Species comparable with the last form have been detected in the Campanian of the Mariana Trench, western Pacific, Leg 60, Site 461 (Kling, 1982, Pl. 6, fig. 9).

The same level also marks the last occurrence of *Amphibrachium sibiricum* Gorbovetz, *Phaseliforma* cf. *carinata* Pessagno, *Excentropylomma* cf. *cenomana* Dumitrica, and *Amphipyndax stoki* (Campbell et Clark) var. B, characteristic of the late Campanian assemblage, the index species of which was found at the top of Bed 2, i.e. somewhat above the separating boundary. In the upper part of the lower Maastrichtian sediments (Bed 5), the assemblage became considerably impoverished and similar in composition to that from the Bulgari section.

Ammonites *Didymoceras schloenbachi* (Favre) and *Nostoceras hyatti* Stephenson were encountered in association with radiolarians of the *Hemicryptocapsa djalilovi* assemblage (Khakimov, 1990, 1998). In the Bulakdasht section, the range of the *Hemicryptocapsa djalilovi* assemblage corresponds to the *Nostoceras hyatti* Zone identified in the Kafirnigan region of the Bukhara-Tajik area (Khakimov, 1998).

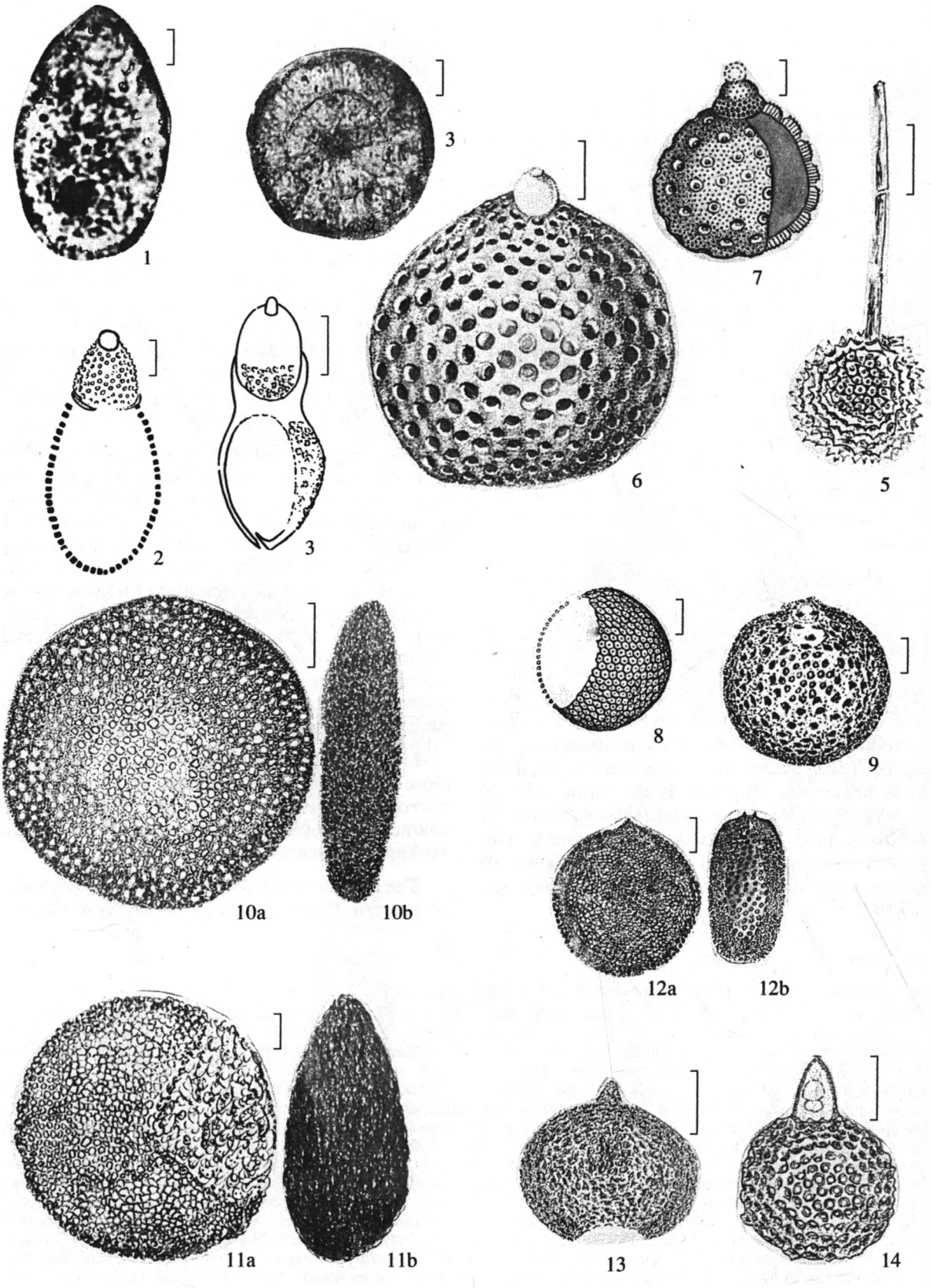
Dzhalilov and Babaeva who worked together with us in the field and studied stratigraphy and lithology assumed that beds 6 to 17 of the Bulakdasht section are identical in lithologic composition to the upper Maastrichtian sediments of the Akdzhar section in the Aruktau Ridge, where the late Maastrichtian *Siderolites calcitrapoides–Orbitoides apiculata* foraminiferal assemblage was described (Ashurov *et al.*, 1987, pp. 523–526). Based on these data, Dzhalilov and Babaeva referred beds 6 to 17 of the Bulakdasht section to the upper Maastrichtian. The Cretaceous–Paleogene boundary is defined above the bed bearing remains of rudist family Radiolitidae.

In bed 11, radiolarian remains are very scarce, but close in species composition to the *Cenosphaera micropora–Holocryptocapsa sp.* assemblage that is characterized below by description of the Bulgari and Verkhnii Khirmanzhou sections.

The Bulgari reference section of the Vakhsh region of eastern Central Asia is situated in the Bulgari

Plate I. *Hemicryptocapsa djalilovi* assemblage of the lower Maastrichtian.

(1) *Hemicryptocapsa djalilovi* Gol'tman, section, smear-slide 8/45, Aktau Ridge (Uzb.); (2) *Gongylothorax tadjikistanensis* var. *spongia* Gol'tman, section, smear-slide 10371/49, Bulgari, Vakhsh Ridge; (3) *Orbiculiforma* cf. *sacramentoensis* Pessagno, smear-slide 21864/57, Bulakdasht, Sarsaryak Ridge; (4) *Orbiculiforma* cf. *renillaeformis* (Campbell et Clark), smear-slide 10371/43, Bulgari, Vakhsh Ridge; (5) *Spongurus* cf. *ocidentalis* Campbell et Clark, smear-slide 99/132, Verkhnii Khirmanzhou, Khozretishi Ridge; (6) *Paronaella* aff. *venadoensis* Pessagno, smear-slide 28/70, Khodzhabaston, northern Karatau Ridge; (7) *Patulibracchium* ex gr. *teslaense* Pessagno, smear-slide 21864/59, Bulakdasht, Sarsaryak Ridge; (8) *?Acidnomelos* ex gr. *laevis* Petrushevskaya, smear-slide 61/8, Chaltau Ridge; (9) *Hemicryptocapsa* ex gr. *pseudopilula* (Tan Sin Hok), smear-slide 102/61, Verkhnii Khirmanzhou, Khozretishi Ridge; (10) *Holocryptocapsa* sp., smear-slide 22064/68, Bulakdasht, Sarsaryak Ridge; (11) *Sethocapsa* cf. *pomum* Squinabol, smear-slide 8268/42, Darbazakam, Aryktau Ridge; (12) *Clathrocyclas* cf. *tintinabulum* (Grigorjeva), smear-slide 765/3b, Aktau Ridge; (13) *?Archicorys* cf. *allodarpe* Foreman, smear-slide 8368/433, Darbazakam, Aryktau Ridge; (14) *Stichomitra* cf. *manifesta* Foreman, smear-slide 21864/61, Bulakdasht, Sarsaryak Ridge; (15) *?Lophophaena* ex gr. *polycyrtis* (Campbell et Clark), smear-slide 21864/55, Bulakdasht, Sarsaryak Ridge; (16) *Stichopilidium* cf. *teslaense* Campbell et Clark, smear-slide 21864/61, Bulakdasht, Sarsaryak Ridge; (17) *Tetracapsa inflata* (Squinabol), smear-slide 21864/62, Sarsaryak Ridge; (18) *Eucyrtis* cf. *Stichomitra micropora* Squinabol), smear-slide 22064/68, Bulakdasht, Sarsaryak Ridge; (19) *Cryptocapsa tricyclia* Rüst, smear-slide 21864/59, Bulakdasht, Sarsaryak Ridge; (20) *?Stichocapsa* ex gr. *livermorensis* Campbell et Clark, smear-slide 21864/59, Bulakdasht, Sarsaryak Ridge; (21) *Cryptocapsa* ex gr. *asymmetra* Foreman, smear-slide 10371/33, Bulgari, Vakhsh Ridge (single and doubled bars are equal to 20 and 50 μm, respectively; figs. 1, 6, 7, 11–17, 19–21—300 μm; figs. 3-5, 8, 18—200 μm, figs. 2, 9, 10 = 600 μm).


1
3
7
6
5
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10a
10b
8
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12a
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11a
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13
14

Depression on the southeastern slope of the Vakhsh Ridge.

Campanian (uppermost part)

Gongylothorax tadjikistanensis Beds (upper part)

(1) Light gray, clayey, finely detrital limestone (10.9 m thick) bearing scarce gypsum concretions and remains of bivalve mollusks, brachiopods, and bryozoans. The sediments contain radiolarians of the *Gongylothorax tadjikistanensis* assemblage (Table 1, column 5).

(2) Greenish gray, carbonate clay 4.2 m thick.

Maastrichtian

Lower Maastrichtian

Hemicryptocapsa djalilovi Beds

(3) Gray clayey detrital limestone (5.1 m thick) bearing remains of bivalve mollusks, brachiopods, bryozoans, and rare *Sulcoperculina* sp.; the unit yields radiolarians of the *Hemicryptocapsa djalilovi* assemblage (Table 1, column 6; Plate I).

(4) Greenish gray, sandy detrital limestone (5.2 m thick) enclosing lenticular coquina beds composed of brachiopod, bivalve, and bryozoan remains; fine-detrital rock varieties yield radiolarians of the *Hemicryptocapsa djalilovi* assemblage. Larger foraminifers *Davisinia primitiva* Hefker, *Orbitoides* sp., and *Textullaria* sp. are found in coarser sediments (Table 1, column 6; Plate I).

(5) Light gray, massive detrital limestone enclosing interlayers composed of *Pycnodonte vesiculare* (Lam.) shells; sediments yield abundant radiolarians of the *Hemicryptocapsa djalilovi* assemblage and larger foraminifers *Davisinia primitiva, Nemkovites darwasensis* (Ashurov), *Siderolites douvillei* Abrard, *Miscellina* sp., and *Sulcoperculina* sp. The upper four meters of the bed are depleted in radiolarian remains. The following scarce forms were found there: *Dorysphaera* cf. *armenica* Kasinzova, *Dorysphaera* sp., *Orbiculiforma* cf. *volgensis* Orb. ex gr. *cachensis* Pessagno, *Cavaspongia* cf. *viminea* Gol'tman, *Spongodiscus minima* Gol'tman, *Gongylothorax tadjikistanensis* var. *spongia, G.* cf. *cephalocrypta* (Tan Sin Hok), *Hemicryptocapsa* cf. *djalilovi* Gol'tman, *Holocryptocanium* sp., and *Cryptamphorella* ex gr. *challengeri* Schaaf. Larger foraminifers *Sulcoperculina dickersoni* (Palmer), *S. globosa* Cizaurt, *Davisinia primitiva* Hofker, *Lepidorbitoides socialis* (Leymerie), *L. minima* (Douvillei), *Nummulites darwasensis* (Ashurov), *Orbitoides* sp. 1, *O.* sp., and *Pseudoorbitoides* sp. The total thickness is 16.0 m.

(6) Light gray, clayey detrital limestone (8.5 m thick) bearing scarce remains of radiolarians *Orbiculiforma* cf. *volgensis* and *Gongylothorax tadjikistanensis* var. *spongia* in association with larger foraminifers *Sulcoperculina dickersoni, S. globosa, S.* sp., *Orbitoides* sp. 1, *O.* sp., and *Pseudoorbitoides* sp.

(7) Light gray to yellowish cavernous limestone (2.0 m thick) bearing internal molds of bivalve mollusks. The total thickness of the lower Maastrichtian is 35.8 m.

Upper Maastrichtian

Siderolites calcitrapoides–Orbitoides apiculata Beds

(8) Light gray, massive detrital limestone (22.0 m thick); presence of bryozoan, coral, and algae colonies is seen in thin sections. The following larger foraminifers were encountered at this level: *Sulcoperculina dickersoni, S. globosa, Orbitoides media* (d'Arch.), *O. apiculata* Schlumb., *O. tissoti* Schlumb., *Lepidorbitoides* ex gr. *mammilata* (Schlumb.), *Pseudoorbitoides vidali* (Douvillei), and *Nemkovites akdjarensis.*

(9) Light gray detrital limestone 10.0 m thick, bearing algae and small bivalves in association with rare *Orbitoides* sp.

(10) Light gray, coarse detrital limestone (15.0 m thick) bearing remains of *Sulcoperculina dickersoni, S. globosa, Orbitoides media, O. tadjikistanensis* Ashurov, *O.* sp., *Pseudoorbitoides* sp., *Omphalocyclus* sp., and *Davisinia* sp.

(11) Light gray, massive fine-detrital limestone (16.0 m thick) bearing rare *Sulcoperculina* sp. and *Orbitoides* sp.; remains of radiolarians *Cenosphaera micropora* (Cayeux), *Dorysphaera longoacantha*

Plate II. Radiolarians of the upper Maastrichtian.

Diacanthocapsa assemblage:

(1) *Diacanthocapsa* cf. *ancus* (Foreman), smear-slide 10371/36, Bulgari, Vakhsh Ridge; (2) *Diacanthocapsa* cf. *teren* (Foreman), smear-slide 22064/72, Bulakdasht, Sarsaryak Ridge; (3) *Diacanthocapsa* ex gr. *ovoida* Dumitrica, smear-slide 109/195, Verkhnii Khirmanzhou, Khozretishi Ridge; (4) *Diploplegma bacciforma* Tschedia, smear-slide 10/50, Aktau ridge (Uzb.); (5) *Dorysphaera longoacantha* Gol'tman, smear-slide 109/193, Verkhnii Khirmanzhou, Khozretishi Ridge; (6) *Sethocapsa* cf. *nobilis* Tan Sin Hok, Preparation EL 2235, Ziddy, Gissarskii Ridge; (7) *Tetracapsa* sp. (ex gr. *Stichocapsa haltaensis* Aliev), smear-slide 109/193, Verkhnii Khirmanzhou, Khozretishi Ridge. *Cenosphaera micropora-Holocryptocapsa* sp. 1 assemblage: (8) *Cenosphaera micropora* Cayeux, smear-slide 107/190, Verkhnii Khirmanzhou, Khozretishi Ridge; (9) *Holocryptocapsa* sp.; (10) *Spongodiscus maximus* Lipman, top view (10a) and side view (10b), smear-slide 10671/63, Bulgari, Vakhsh Ridge; (11) *Orbiculiforma* cf. *volgensis* (Lipman), top view (11a) and side view (11b), Preparation EL 2014, Sample 2911, Balakhana; (12) *Spongodiscus minima* Gol'tman, top view (12a) and side view (12b), Preparation EL 928, Sample 8/199, Alchasai; (13) *Dictyocephalus* cf. *cayeuxi* Squinabol, smear-slide 14/19, Kabutak, Khozretishi Ridge; (14) *Squinabollum* cf. *fossilis* (Squinabol), smear-slide 99/142, Verkhnii Khirmanzhou, Khozretishi Ridge (single and doubled bars are equal to 20 and 50 μm, respectively; figs. 1, 2, 4, 7–9, 11, 12—300 μm, figs. 3, 6, 10—200 μm, figs. 5, 13, 14—600 μm).

Gol'tman, *Spongodiscus maximus* Lipman, and *Holocryptocapsa* sp. are identified in the upper three meters of the bed.

(12) Light gray, massive detrital limestone (15.0 m thick) bearing foraminifers *Sulcoperculina dickersoni, S. dickersoni vermunti* (Tiad.), *S.* sp., *Orbitoides apiculata, Pseudoorbitoides* sp., *Pseudosiderolites vidali, P.* sp., *Nemkovites djalilovi* Ashurov, *N. akdjarensis* Ashurov, *Nummulites* sp., and *Miscellina* sp.; the lowermost two meters of the bed yield radiolarians *Cenosphaera micropora, Dorysphaera longoacantha, Spongodiscus maximus*, and *Holocryptocapsa* sp. (Table 1, column 9; Plate II).

(13) Light gray fine-detrital limestone (2.0 m thick) bearing radiolarians *Spongodiscus minima, S. maximus*, and *Holocryptocapsa* sp.

(14) Light gray, coarse detrital limestone (7.3 m thick) bearing remains of bryozoans and algae.

(15) Light gray, coarse at the base, detrital limestone (20.2 m thick) with abundant remains of *Pycnodonte vesiculare*, bryozoans, and algae branches. Larger foraminifers *Sulcoperculina dickersoni, S. globosa, S. dickersoni vermunti, Orbitoides apiculata, O. tadjikistanensis, O.* sp., *Lockhardia roestae* (Visser), and *Lepidorbitoides* cf. *minima* are distinguished in the bed. In the lowermost 12 m, there are radiolarians of the *Cenosphaera micropora–Holocryptocapsa* sp. assemblage (Plate II). In addition to index species, the assemblage includes *Dorysphaera longoacantha, Orbiculiforma* cf. *volgensis, Porodiscus* cf. *vulgaris* Lipman, *Cryptamphorella* ex gr. *sphaerica, Holocryptocanium* cf. *japonicum* Nakaseko et Nishimura, and *Clathrocyclas* ex gr. *tintinabulum* (Table 1, column 9). Rudist remains were found at the top of the unit.

Beds 11–15 bearing the *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage are 36.3 m thick in total. The total thickness of the *Siderolites calcitrapoides–Orbitoides apiculata* Beds is 107.5 m.

Biradiolites boldjuanensis Beds

(16) Limestone light gray at the base and pink above (10.7 m thick) bearing abundant rudists *Biradiolites boldjuanensis* Bobkova, *B.* cf. *lameracensis* Toucas, *Lapeirouseia boldjuanensis* Bobkova, and *Praeradiolites simakovi* Bobkova in the lower part, according to Bobkova (1974). Dzhalilov (1971) also identified here *Biradiolites boldjuanensis* Bobkova and *Orbignia* ex gr. *vlasovi* Bobkova. The following radiolarians were found near the base of the unit: *Cenosphaera* cf. *micropora, Cryptamphorella* sp., *Orbiculiforma* cf. *volgensis, Gongylothorax* sp., *Clathrocyclas* ex gr. *tintinabulum, Porodiscus* cf. *vulgaris, Hemicryptocapsa* sp. 1, and *Tetracapsa* sp. (cf. *Stichocapsa haltaensis* Aliev). Composition of radiolarian species is similar to that of the *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage (Table 1, column 9; Plate II).

(17) Hard pinkish, spotted brown, platy limestone (1.1 m thick) bearing remains of bivalves *Pycnodonte vesiculare, Inoceramus* sp. ind., *Pholadomya* sp. ind., and *Tellina* sp. ind.

(18) Light gray massive limestone (2.5 m thick) with two interlayers of detrital limestones; remains of oysters *Pycnodonte vesiculare* and *Ceratostreon spinosum* Math. are identified. The overlying sediments are hidden under talus. The total thickness of the *Biradiolites boldjuanensis* beds is 14.3 m. The upper Maastrichtian is 121.6 m thick, and total thickness of the Maastrichtian is 156.6 m.

The *Hemicryptocapsa djalilovi* assemblage of the Bulgari section is considerably less diverse than that of the Bulakdasht section. Along with the index species, it includes the following characteristic forms: *Spongurus ocidentalis, Orbiculiforma* cf. *renillaeformis, O.* cf. *cachensis, Porodiscus* cf. *vulgaris, Dicolocapsa* sp. 1, *Dorysphaera* cf. *armenica, Patulibracchium* cf. *teslaensis, Pseudoaulophacus* cf. *parquerensis* Pessagno, *Paronasella* cf. *venadoensis* Pessagno, *Gongylothorax* cf. *cephalocrypta, Sethocapsa* aff. *nobilis, S. pomum, Theocampe* ex gr. *salilum* Foreman, *Eucyrtis* ex gr. *fusiformis* Hinde, *Clathrocyclas* cf. *tintinabulum, ?Acidnomelos* cf. *laevis* Petrushevskaja, *Novixitus* sp. B, *Squinabollum fossilis* Squinabol, *Archicorys* cf. *allodarpe* Foreman, and *Homeoarchicorys* cf. *eiformigum* Empson-Morin (Table 1, column 9; Plate I). Distribution of most species is characterized above, in description of the Bulakdasht section. *Theocampe salilum* is known from the Campanian sediments of the Pacific. In addition, this species is rather widespread in the Campanian and Maastrichtian of the Pacific (Leg 32; Leg 60, Site 452) (Kling, 1982; Foreman, 1977, 1978). *Novixitus* sp. is recorded in the Campanian of Austria; *Homeoarchiceris eiformigum* was found at Site 313 in the Pacific and *Acidnomelos laevis* in the upper Campanian–Maastrichtian of the southwestern Pacific, Leg 21, Site 275 (Petrushevskaya, 1977). *?Archicorys allodarpe* is an upper Maastrichtian known in the Californian coast of America (Foreman, 1968). The upper limit of the *Gongylothorax tadjikistanensis* assemblage is marked by the extinction of many characteristic late Campanian species (Table 1) and by the appearance of the following forms typical of the *Hemicryptocapsa djalilovi* assemblage: *Patulibracchium* cf. *teslaensis, Pseudoaulophacus* cf. *parquerensis*, numerous *Gongylothorax tadjikistanensis spongia, Eucyrtis* ex gr. *fusiformis*, and others. The last occurrences of *Amphibrachium sibiricum, A. spongiosum* Lipman, *Phasseliforma* cf. *carinata, P. foremanae* Gol'tman, and *Crucella* cf. *aster* (Lipman) are also recorded here. Abundance of *Cryptamphorella* cf. *challengeri* Schaaf substantially increases at the same level. Dominant in the *Hemicryptocapsa djalilovi* assemblage of the Bulgari section are Eucyrtidae and less abundant Williriedelidae. In the upper part of the *Hemicryptocapsa djalilovi* Beds, the species diversity markedly declines. This decline coincides with the appear-

ance of larger foraminifers, and radiolarians disappear at the top of Bed 7. Foraminifers of the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage, which were identified by Ashurov in the Gol'tman's collections, are numerous in massive limestones of beds 8–15. Like in the Akdzhar section (Ashurov *et al.*, 1987), several horizons bearing larger foraminifers remains are recognized.

The mid-upper Maastrichtian sediments yield radiolarians attributed in this work to the *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage. Gol'tman (1988) defined them previously as the "c" group of the *Hemicryptocapsa djalilovi* assemblage. However, a considerable difference between the groups in species composition and age are used as arguments in favor of discrimination of a separate radiolarian assemblage (Plate II).

Many species of the assemblage are known from the underlying sediments as well. The distinctive feature of assemblage is predominance of *Cenosphaera micropora, Holocryptocapsa* sp. 1, *Spongodiscus minima*, and *Orbiculiforma* cf. *volgensis*. In addition, *Spongodiscus maximus, Sethocapsa pomum, S.* cf. *nobilis, Amphipyndax* sp., *Tetracapsa* sp. (cf. *Stichocapsa haltaensis*), *Squinabollum* cf. *fossilis*, and *Dictyocephalus* cf. *cayeuxi* are characteristic of the section interval under discussion. *Holocryptocapsa* sp. 1 was found in the Campanian of the western Pacific and Indian Ocean (Renz, 1977; Kling, 1982), whereas *Cenosphaera micropora* occurs in concurrent deposits of Belgium. *Spongodiscus maximus* is known from the Santonian and Maastrichtian of the Russian platform. *Dictyocephalus cayeuxi* and *Squinabollum fossilis* are described from the Senonian of Sicily. The *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage characteristic of the uppermost *Siderolites calcitrapoides–Orbitoides apiculata* Beds suggests the late Maastrichtian age of enclosing sediments (Ashurov *et al.*, 1987; Ashurov, 1991).

An assemblage similar in specific composition was encountered in the Bulakdasht section (Table 1), where the radiolarian *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage is also attributed to the upper Maastrichtian (Table 1, column 8).

The Verkhnii Khirmanzhou section is situated in the southeastern Khozretishi Ridge. The following units are established here (from the base upward).

Campanian (uppermost part)

Gongylothorax tadjikistanensis beds

(1) Light gray, clayey at the base and fine-detrital in places limestone bearing phosphorite and glauconite grains. Remains of bivalve mollusks and coral colonies (up to 1 m) occur in the lower part of the unit. The overlying limestones are massive, bioclastic, and contain bryozoans. The top of the unit bears erosion marks. Sediments yield abundant and diverse radiolarians of the *Gongylothorax tadjikistanensis* assemblage. Larger foraminifer species *Sulcoperculina globosa* Cizancourt are also encountered. The total thickness is 30.0 m.

Maastrichtian

Lower Maastrichtian

Hemicryptocapsa djalilovi Beds

(2) Dark gray to black clayey detrital limestone (22.0 m thick) bearing abundant *Pycnodonte vesiculare* valves near the base and large oyster shells *Lopha* sp. accumulated in lenses. Remains of large echinoids occur as well. The overlying detrital limestones are coarse-grained. The unit yields abundant radiolarians of the *Hemicryptocapsa djalilovi* assemblage (Table 1, column 7; Plate I). Larger foraminifers *Sulcoperculina dickersoni* and *S. globosa* are less abundant.

(3) Pinkish gray, massive dense bioclastic limestone (8.3 m thick) with abundant oysters *Pycnodonte vesiculare* and remains of large coral colonies. Sediments yield radiolarians of the *Hemicryptocapsa djalilovi* assemblage (Table 1, column 7) and larger foraminifers *Sulcoperculina* sp., *Operculina* sp., *Nemkovites djalilovi, N. darvasensis* (Ashurov), *Orbitoides tissoti, Nummulites* sp., and *Siderolites calcitrapoides* Lam. near at the top. The total thickness of the lower Maastrichtian is 30.3 m.

Siderolites calcitrapoides–Orbitoides apiculata Beds

(4) Pinkish gray, massive bioclastic limestone (20.0 m thick) bearing abundant *Pycnodonte vesiculare* shells and scarce remains of large coral colonies. A ferruginate zone with filled pockets (up to 5 cm) marks the erosional unconformity at the base of the unit. Sediments within the lower 7 m yield rare radiolarians *Spongodiscus minima, Bullacapsa* sp., and *Syringocapsa* sp. Scarce *Dicolocapsa* sp. 1 and *Hemicryptocapsa* sp. in association with larger foraminifers *Sulcoperculina dickersoni, S. globosa, S.* sp., *Orbitoides tadjikistanensis, O. apiculata, Nemkovites akdjarensis, Lockhardia roestae*, and *Nummulites* sp. were found near the top. *Orbitoides apiculata* was also detected at the base of the unit.

Cenosphaera micropora–Holocryptocapsa sp. 1 Beds

(5) Pinkish gray bioclastic limestone (10.0 m thick) bearing large rudist remains at the base; in the lower one-third of the unit, sediments yield abundant radiolarians *Cenosphaera micropora, Spongodiscus minima*, and less common *Orbiculiforma volgensis, Holocryptocapsa* sp. 1, *Dorysphaera* cf. *armenica, Porodiscus* cf. *vulgaris, Hemicryptocapsa* cf. *djalilovi*, and *Spongodiscus maximus. Sulcoperculina* sp. and *Orbitoides apiculata* (Table 1, column 10; Plate II) were found near the unit base. The thickness of the *Cenosphaera micropora–Holocryptocapsa* sp. 1 beds is 10.0 m.

(6) Pinkish gray bioclastic limestone (21.5 m thick) bearing remains of *Sulcoperculina globosa, S. dicker-*

soni, and *Nemkovites djalilovi* in the upper 10 m. Numerous rudist and brachiopod remains occur at the level of 4 m below the top. The total thickness of the *Siderolites calcitrapoides–Orbitoides apiculata* Beds is 51.5 m.

Biradiolites boldjuanensis Beds

(7) Gravelstone (10.0 m thick) overlying the eroded surface. The matrix is composed of bioclastic limestone with remains of brachiopod and rudist shells. Pebbles (up to 2 cm across) are represented by red quartz sandstone with fragments of igneous rocks.

(8) Brecciated, spotted and light in places, lumpy limestone (6.5 m thick) bearing abundant rudist fragments and pebbles of Paleozoic rocks.

(9) Brownish gray sandy limestone (3.3 m thick) showing presence of numerous glauconite grains and vague cross-bedding.

(10) Brownish gray, bioclastic, coarse-grained limestone (8.6 m thick), composed of bryozoans and crinoids, and commonly bearing fragments of rudists and other bivalve mollusks. Scarce radiolarians *Cenosphaera micropora* and *Diploplegma bacciforma* Tschedia are present.

Diacanthocapsa Beds

(11) Brick-red limestone (2.8 m thick) composed of rudist remains. In this part of the section, Bobkova (1974) identified species *Vasconites lamarcki* Bayle et Douvillei, *Orbignia simakovi* Pojarkova, *O. vlasovi* Bobkova, *Biradiolites boldjuanensis* Bobkova, and others.

(12) Brick-red siltstone grading into brick-red limestone (1.2 m thick) that bears rare rudist remains.

(13) The above rocks grade into gray and brick-red calcareous siltstone (2.5 m thick).

Smear-slides of calcareous siltstones from beds 11 to 13 show presence of radiolarians *Cenosphaera micropora, Dorysphaera longoacantha, Diploplegma bacciforma, Tetracapsa* sp. (cf. *Stychocapsa haltaensis*), *Sethocapsa nobilis, Diacanthocapsa* cf. *ancus, D.* cf. *teren* (Foreman), and *D.* cf. *amphora* (Table 1, column 13; Plate II). The total thickness of the *Biradiolites boldjuanensis* beds is 36.2 m. The total thickness of the upper Maastrichtian is 87.7 m.

A detailed analysis of the Maastrichtian radiolarians and larger foraminifers from the Verkhnii Khirmanzhou section was done earlier (Gol'tman and Ashurov, 1989). New data refine the former results. The *Hemicryptocapsa djalilovi* assemblage is correlated with that of the Bulakdasht section (refer to Table 1). The lower distribution limit of the assemblage is defined by appearance of *Spongurus ocidentalis, Spongodiscus maximus, Dorysphaera longoacantha, Sethocapsa pomum*, and *Squinabollum fossilis*, and by a considerable increase in abundance of *Gongylothorax tadjikistanensis* var. *spongia* at the base of Bed 2. The replacement of the Campanian by Maastrichtian assemblage coincides with the base of Bed 23, as suggested by Gol'tman and Ashurov (1989). The assemblage is also characterized by presence of *Hemicryptocapsa djalilovi, Dorysphaera* cf. *armenica, Porodiscus* cf. *vulgaris, P.* ex gr. *delicatulus, Orbiculiforma* cf. *volgensis, Dicolocapsa* sp. 1, *Spongodiscus minima, Syringocapsa* sp., *Homeoarchicoris* cf. *eiformigum, Stylocapsa* cf. *hastellata, Holocryptocanium* sp. 1, *Diacanthocapsa* cf. *granti*, and *Dictyocephalus* cf. *cayeuxi* (Table 1; Plate II). Dominant in the assemblage are Williriedellidae and Eucyrtidiidae species, like in the western sections. Among the forms mentioned above, *Spongurus ocidentalis* and *Diacanthocapsa granti* are known from the Maastrichtian of the Californian coast of the United States (Campbell and Clark, 1944), *Homeoarchicorys eiformigum* from the Campanian-Maastrichtian sediments of the Pacific (Leg 31), and *Holocryptocaps* sp. 1 from the Campanian of the Rumanian Carpathians (Dumitrika, 1971). The Campanian-Maastrichtian boundary marks the last occurrence of *Amphibrachium sibiricum, A. spongiosum*, and *Crucella* cf. *aster.*

Thus, the species composition of the *Hemicryptocapsa djalilovi* assemblage, though considerably impoverished, and transition from the Campanian and Maastrichtian beds in the Verkhnii Khirmanzhou section are identical to those of the western sections.

Based on findings of brachiopods *Praeneothyris subdepressa* (Stol.) and *P. subovalis* Katz known from the lower Maastrichtian *lanceolate* Zone of the Amudar'ya River lower reaches, Dzhalilov (1963) previously referred the thick limestone sequence of the southwestern Darvaz to the lower Maastrichtian. More recently, Dzhalilov (1971) distinguished the local, presumably lower Maastrichtian, *Praeneothyris subdepressa* Zone roughly correlated with Beds 3–7 of the Verkhnii Khirmanzhou section, which most likely correspond to the uppermost *Hemicryptocapsa djalilovi* and *Siderolites calcitrapoides–Orbitoides apiculata* beds. This interval corresponds to a part of the lower and upper Maastrichtian. As in the Bulgari section, the radiolarian assemblage becomes substantially impoverished, finally to their complete extinction, at the appearance level of larger foraminifers of the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage. The species composition of foraminifers was reported earlier (Gol'tman and Ashurov, 1989), and age of the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage is determined as the late Maastrichtian (Ashurov, 1991).

Radiolarians from the next interval (Bed 5 corresponding to bed 26 in Gol'tman and Ashurov, 1989) represent the *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage. It is characterized by predominance of *Cenosphaera micropora, Orbiculiforma* cf. *volgensis*, and *Spongodiscus minima*, whereas *Holocryptocapsa* sp. 1, *Dorysphaera* cf. *armenica, Porodiscus* cf. *vulgaris*, and *Gongylothorax tadjikistanensis* var. *spongia* are rare. The uppermost part of the assem-

Table 2. Stratigraphic ranges of upper Campanian and Maastrichtian faunal assemblages in the southeastern Tajik depression

Stage		Mollusks	Foraminifers	Radiolarians
Maastrichtian	upper		*Siderolites calcitrapoides–Orbitolites apiculata*	*Cenosphaera micropora–Holocryptocapsa* sp. 1
	lower	*Nestoceras hyatti*		*Hemicryptocaspa djalilovi*
Campanian	upper	*Trachiscaphites pulchcerimus*		*Gondylothorax tadjikistanensis*
		Hoplitoplacenticeras marroti		

blage range is marked by the first occurrence of *Diacanthocapsa* cf. *teren* and *D.* cf. *ancus* known from the upper Maastrichtian of the Californian coast in America and East Atlantic shelf (Foreman, 1968, 1978).

The top of bed 5 is characterized by appearance of rudists in a considerable amount, which occur in beds 9–12 as well. In this part of the Verkhnii Khirmanzhou section, Bobkova (1974) described the fifth rudist horizon that yielded, along with hippurid shells, abundant remains of *Biradiolites boldjuanensis* Bobkova. Dzhalilov (1971) distinguished in this part of the section the local *Biradiolites boldjuanensis* Zone.

Beds 11–13 contain scarce radiolarians *Cenosphaera micropora, Diploplegma bacciforma, Dorysphaera longoacantha, Tetracapsa* sp. (cf. *Stichocapsa haltaensis*), *Sethocapsa* cf. *nobilis, Diacanthocapsa* cf. *ancus, D.* cf. *amphora*, and *D.* cf. *teren* (Table 1, column 13; Plate II). It should be noted that three latter species were first described from the upper Maastrichtian of the Californian coast, *Diacanthocapsa* cf. *teren* is known from the upper Maastrichtian of the eastern Atlantic (Foreman, 1968, 1978), and *Diploplegma bacciforma* is abundant in the Paleocene of the Tajik depression (Chediya *et al.*, 1971).

Thus, the studied radiolarians, ammonoids, and larger foraminifers revealed a certain succession of faunal assemblages in the sections of the eastern Tajik depression, the southwestern Darvaz included (Table 2).

The distinguished radiolarian assemblages mark three Maastrichtian levels of their development in the study region. The first one associated with the *Hemicryptocapsa djalilovi* assemblage is recorded in the lowermost Maastrichtian. The difference in species composition of the upper Campanian *Gongylothorax tadjikistanensis* and next *Hemicryptocapsa djalilovi* assemblage is rather distinct, as can be seen in Table 1. In the former assemblage, predominant spongurids, euchitonids, and chagiastrids coexist with rather abundant Williriedellidae representing nassellarians, whereas the latter one is marked by diversification of Eucyrtidiidae species (see Table 1). Williriedellidae are less diverse though rather numerous in the last case. In addition to the index species, *Spongurus ocidentalis, Orbiculiforma* cf. *sacramentoensis, O. renillaeformis, Patulibracchium* cf. *taliaferroi*, and *Paronaella venadoensis* are characteristic of the *Hemicryptocapsa djalilovi* assemblage. It also includes a substantial amount of *Gongylothorax tadjikistanensis* var. *spongia.* Among nassellarians, there are *Gongylothorax* cf. *cephalocrypta, Dicolocapsa* sp. 1, *?Lophophaena* cf. *polycyrtis, ? Stichocapsa* cf. *livermorensis, Clathrocyclas tintinabulum, Archicorys* cf. *allodarpe, Acidnomelos* ex gr. *laevis, Diacanthocapsa* cf. *granti, Holocryptocanium* sp. 1, and other species (Table 1, columns 5–7; Plate I). Most of the listed forms are either zonal species, or taxa known from the Maastrichtian of different regions. For instance, *Orbiculoforma renillaeformis* (Pessagno, 1976) is a zonal species from the Californian coast of North America, and *Clathrocyclas tintinabulum* is a key taxon of synonymous zone in central Russia and Sakhalin (Kasinzova and Vishnevskaja, 1988). Age of the *Hemicryptocapsa djalilovi* assemblage is controlled in the Bulakdasht section by coexisting ammonoid zonal species *Nostoceras hyatti* and *Didymoceras schloenbachi* (Favre). According to Khakimov (1998, p. 39), *Nostoceras hyatti* "is recorded in the lower Maastrichtian of the Aquitanian basin, being characteristic of the R_2 horizon (Maastrichtian) of the Arnau scheme. In addition, the species was reported from the lower Maastrichtian of inner regions of the United States and Angola... Stratigraphic range of *Didymoceras schloenbachi* (Favre) spans the lower Maastrichtian *Belemnella lanceolata, B. pseudoobtusa*, and *B. obtusa* zones." Thus, the range of the *Hemicryptocapsa djalilovi* assemblage is limited by the lower Maastrichtian. In the Tajik depression, the assemblage is known from its central and eastern parts. In the southwestern Darvaz, its range most likely corresponds to the lower beds of the local *Praeneothyris subdepressa* Zone (Dzhalilov, 1963). In this work, we did not pay special attention to the problem of the *Hemicryptocapsa djalilovi* assemblage range. Nevertheless, in the Aktau and western Akdzhar sections of the central Tajik depression, where species composition of radiolarians was studied earlier (Dzhalilov, 1988), the lower sediments enclosing the assemblage are referred to the upper Campanian.

Comparing distribution ranges of the assemblage in the Bulakdasht and the more western Aktau section, we emphasized that its lower limit in the latter is defined by

appearance of *Orbiculiforma* ex gr. *renillaeformis, Spongodiscus minima*, and *Tetracapsa* cf. *inflata* in association with abundant *Gongylothorax tadjikistanensis* var. *spongia*, and by the last occurrence of *Histiastrum* cf. *aster, ?Zhamoidellum demissicium*, and *Hemicryptocapsa verrucata*. This level corresponds to the lower part of Bed 7. The index species appeared somewhat higher like in the eastern sections. The upper distribution limit of the assemblage is similar to that established in the Bulgari and Verkhnii Khirmanzhou sections, where it marks a gradual disappearance of radiolarians and appearance of the *Siderolites calcitrapoides–Orbitoides apiculata* foraminiferal assemblage. In the western Aktau section, this is the interval of Bed 9.

Therefore, beds 7–9 described by Dzhalilov (1988, p. 12) can be correlated with deposits bearing the *Hemicryptocapsa djalilovi* assemblage. Bed 9 of the Akdzhar section in the Aruktau Ridge (Dzhalilov, 1988, p. 18) most likely corresponds to this age interval as well. Accordingly, we conclude that the upper layers of the Daralitau Horizon in the sections of the central Tajik depression, which yield the *Hemicryptocapsa djalilovi* assemblage, should be referred to the lower Maastrichtian.

In the Bulgari and Verkhnii Khirmanzhoy sections of the eastern Tajik depression, the radiolarian assemblage is replaced by larger foraminifers of the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage (see description of the sections and Table 2). In the Bulakdasht site this part of the sequence corresponds to the interval of alternating limestone and dolomite beds concurrent to the same event in the Akdzhar section. Ashurov noted that "*Siderolites calcitrapoides* Lam., *Omphalocyclus macroporus* (Lam.), *Orbitoides apiculata*, and *O. media* Arch. occur in zones Mb, Mc, and Md of the Maastrichtian stratotype of Holland. ... these zones correspond to the upper part of the *Belemnitella junior* Zone coupled with the lower part of the upper Maastrichtian *Neobelemnella kazimiroviensis* Zone" (Ashurov, 1991, p. 121). On these grounds, he suggested to place the lower–upper Maastrichtian boundary at the base of the beds bearing larger foraminifers (Ashurov, 1991). We emphasize therewith that in all studied sections the appearance of larger foraminifers is accompanied by a considerable impoverishment or disappearance of the lower Maastrichtian radiolarian assemblage.

Thus, we observe the following biostratigraphic succession in the eastern sections: the upper Campanian *Gongylothorax tadjikistanensis* assemblage is replaced by the lower Maastrichtian *Hemicryptocapsa djalilovi* assemblage, and then the latter gives place to the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage of larger foraminifers (see Table 2).

The next interval of radiolarian abundance is recorded in the mid-upper Maastrichtian (Table 2) and corresponds to upper horizons bearing larger foraminifers.

Gol'tman (1988) previously described radiolarians from this part of the section as the "c" group of the *Hemicryptocapsa djalilovi* assemblage. However, a considerable break between findings, peculiar species composition, and age difference allowed her to distinguish a separate *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage (Plate II). The assemblage shows predominance of one or several following species: *Cenosphaera micropora, Holocryptocapsa* sp. 1, *Spongodiscus minima*, and *Orbiculiforma* cf. *volgensis*. The first one has been described from the lower Campanian of Belgium, *Holocryptocapsa* sp. 1 is recorded in the Campanian of the western Pacific (Kling, 1982; *Atlas...*, 1998), and *Orbiculiforma volgensis* is widely known from the Senonian of the Russian platform and West Siberian Lowland. The assemblage commonly includes *Spongodiscus maximus* described from the Santonian and Maastrichtian of the Russian platform, *Sethocapsa nobilis* known from the Senonian of Java, *Amphipyndax* sp. recorded in the Maastrichtian of the eastern Atlantic (Site 369A), and some other species. The range of the *Cenosphaera micropora-Holocryptocapsa* sp. 1 assemblage is limited by uppermost beds yielding foraminifers of the *Siderolites calcitrapoides–Orbitoides apiculata* assemblage. Earlier Gol'tman (1988) noted a wide distribution of the assemblage in both calcareous and silty sediments of the Tajik depression. At the same time, the assemblage coexists with the upper Maastrichtian foraminiferal assemblage, and the *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage can be of the late Maastrichtian age.

In the Bulgari and Verkhnii Khirmanzhou sections of the eastern Tajik depression, the assemblage of larger foraminifers is found distinctly below the *Biradiolites boldjuanensis* assemblage of rudists. Describing the fifth rudist horizon, Bobkova (1974) noted presence of *Biradiolites* cf. *lameracensis* Thoucas, and *Vassinites lamarcki* Bayle et Douvillei, all characteristic of the Maastrichtian in France. This suggests the Maastrichtian age of the *Biradiolites boldjuanensis* Beds, and their position above the beds with larger foraminifers implies the late Maastrichtian age of the rudist horizons.

Radiolarians are rare in red limestones and calcareous siltstones at the top of the rudist beds and in overlying siltstones (Table 1; Plate II). *Diacanthocapsa ancus, D. amphora*, and *D. teren* occurring among them have been described from the upper Maastrichtian of the Californian coast of America and are known from the upper Maastrichtian of the eastern Atlantic (Foreman, 1968, 1978). These data confirm the late Maastrichtian age of enclosing sediments.

New data on composition and distribution of the radiolarian *Hemicryptocapsa djalilovi* assemblage imply its Maastrichtian age, though coexisting ammonoids of the *Nostoceras hyatti* Zone restrict the dating to the early Maastrichtian. The upper Campanian–lower Maastrichtian boundary in the eastern Tajik depression is defined at the level separating the *Gongylothorax tadjikistanensis* and *Hemicryptocapsa djalilovi* radiolarian assemblages. The lower–upper Maastrichtian boundary is found within the interval, where the latter gradually gives place to the *Siderolites calci-*

trapoides–Orbitoides apiculata assemblage of larger foraminifers (see Table 2). The range of the radiolarian *Cenosphaera micropora–Holocryptocapsa* sp. 1 assemblage is correlated with the middle part of the upper Maastrichtian. The findings of upper Maastrichtian radiolarians in the lowermost red siltstones suggest that accumulation of red beds begun in the late Maastrichtian.

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BRIEF COMMUNICATIONS

The Quaternary Malacofauna from the Sangachal Section (Southwestern Caspian Sea Coast)

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Key words: Caspian Sea, malacofauna locality, Apsheronian, Pleistocene, molluscan assemblages, marine terraces.

Stratigraphy of the Apsheronian deposits of the Caspian Sea region is completely based on malacofauna distribution throughout the sections. Fossil mollusks found in the Caspian coast sections are abundant, but they are usually isolated and thus of low use for subdivision and correlation of host deposits. The Sangachal section located at the Kobystan coast of Azerbaijan represents a lucky exception, because it is composed of the Apsheronian, early Khazarian (Gyurgyan), late Khvalynian, and Neocaspian sediments of brackish-water basins, which are well characterized in paleontological aspect (Fig. 1).

The section is situated 5 km northeast of the Cape Sangachal. In terms of geomorphology, this is an outlier of the late Khvalynian abrasive terrace with the surface located 12 m above the modern Caspian Sea level (abs. mark –27 m) and composed of Apsheronian and underlying Paleocaspian strata dipping southeastward at the angle of 10°–15°. The seaward side of the outlier is abraded, having a step–clumpy bench at the water base level. In the Neocaspian time, this sector of the shore was also subjected to abrasion that formed an abrasive terrace located about 4 m above the Caspian Sea level and bounded in its rear part by the cliff with wave-cut local niche.

In the northwestern, landward side, there is a quarry, where sands occurring above the Apsheronian sediments (their characteristic is given below) were mined. Further landward, the surface of the abrasive terrace slightly lowers and grades into the coastal plain of the late Khvalynian age that is universally developed in depressions of the Kobystan coast and is -16 m high (abs. mark). Southwestward, the outlier of the late Khvalynian abrasive terrace is adjoined by partly deflated surface of the Neocaspian terrace that has the relative height of about 3–5 m and is up to 100–150 m wide in areas where it spreads to the mouth area of a small river flowing into the Caspian Sea.

The surface of the Neocaspian terrace is adjoined by the modern beach about 20 m wide and consisting of two offshore bars. Beach deposits are mainly composed of dark brown oolitic sands with an admixture of shelly material. The river mouth opens into a small lagoon that was formed by blocking of the river by an offshore bar.

The Apsheronian section with excellent paleontological remains is exposed in the abrasive bench of the seaward part of the outlier. The following succession of beds is observable here from the base upward (see Fig. 2):

(1) Silt, dark gray to brown, compact, with abundant intact and broken molluscan shells, sometimes forming

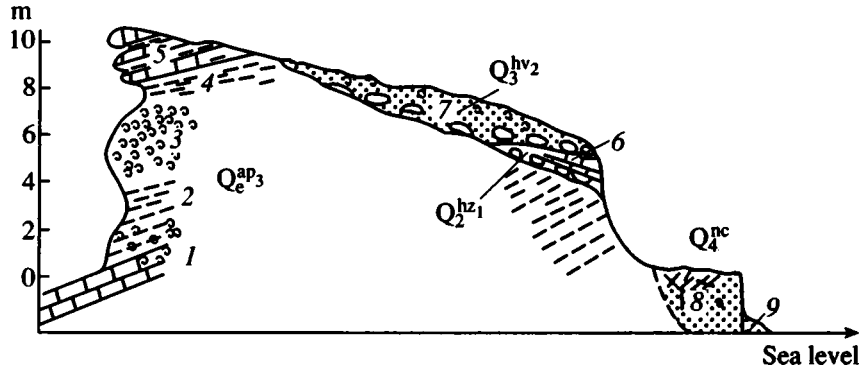


Fig. 1. Studied localities with fossil malacofauna (see explanation to symbols in Fig. 2).

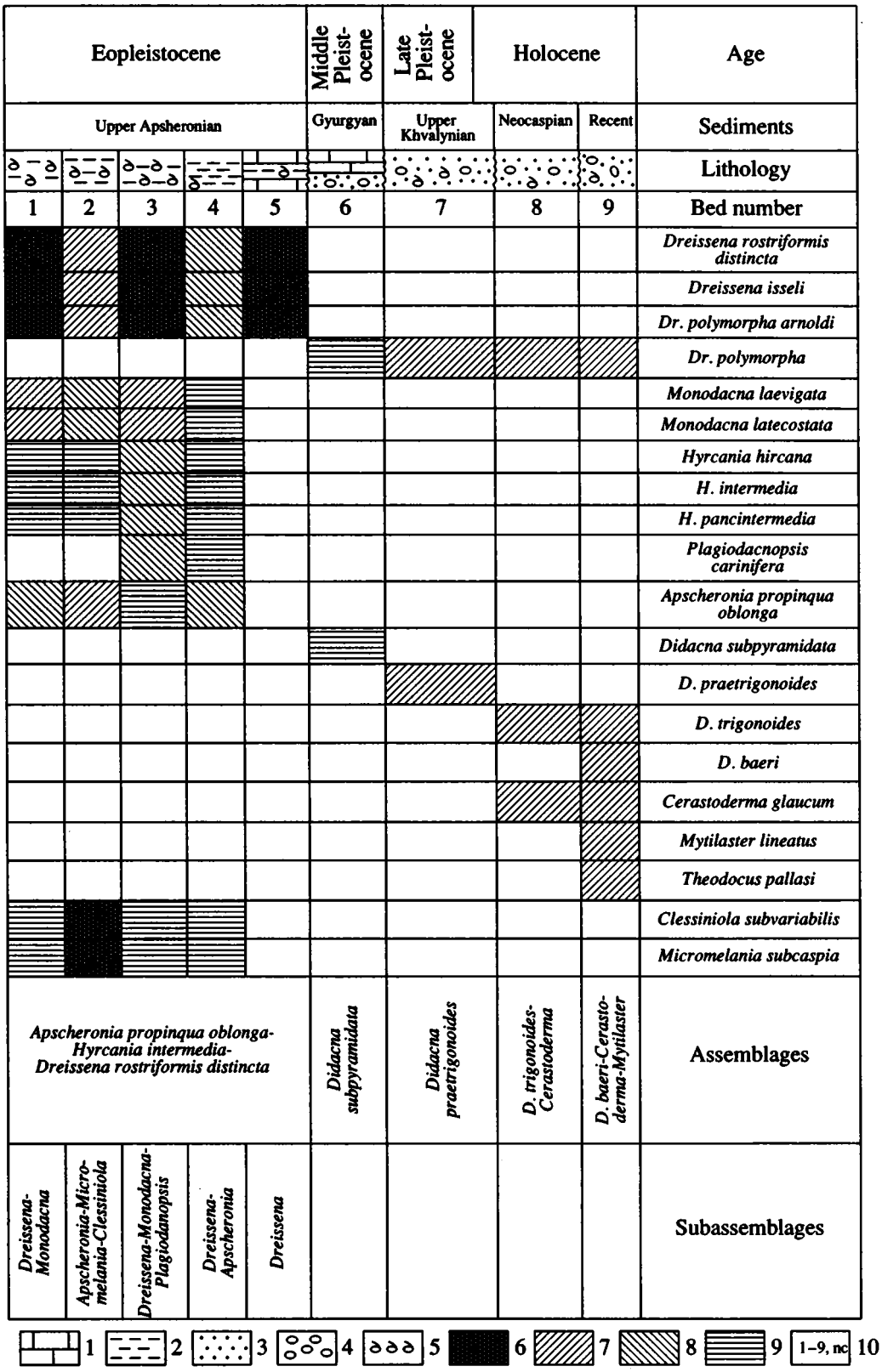
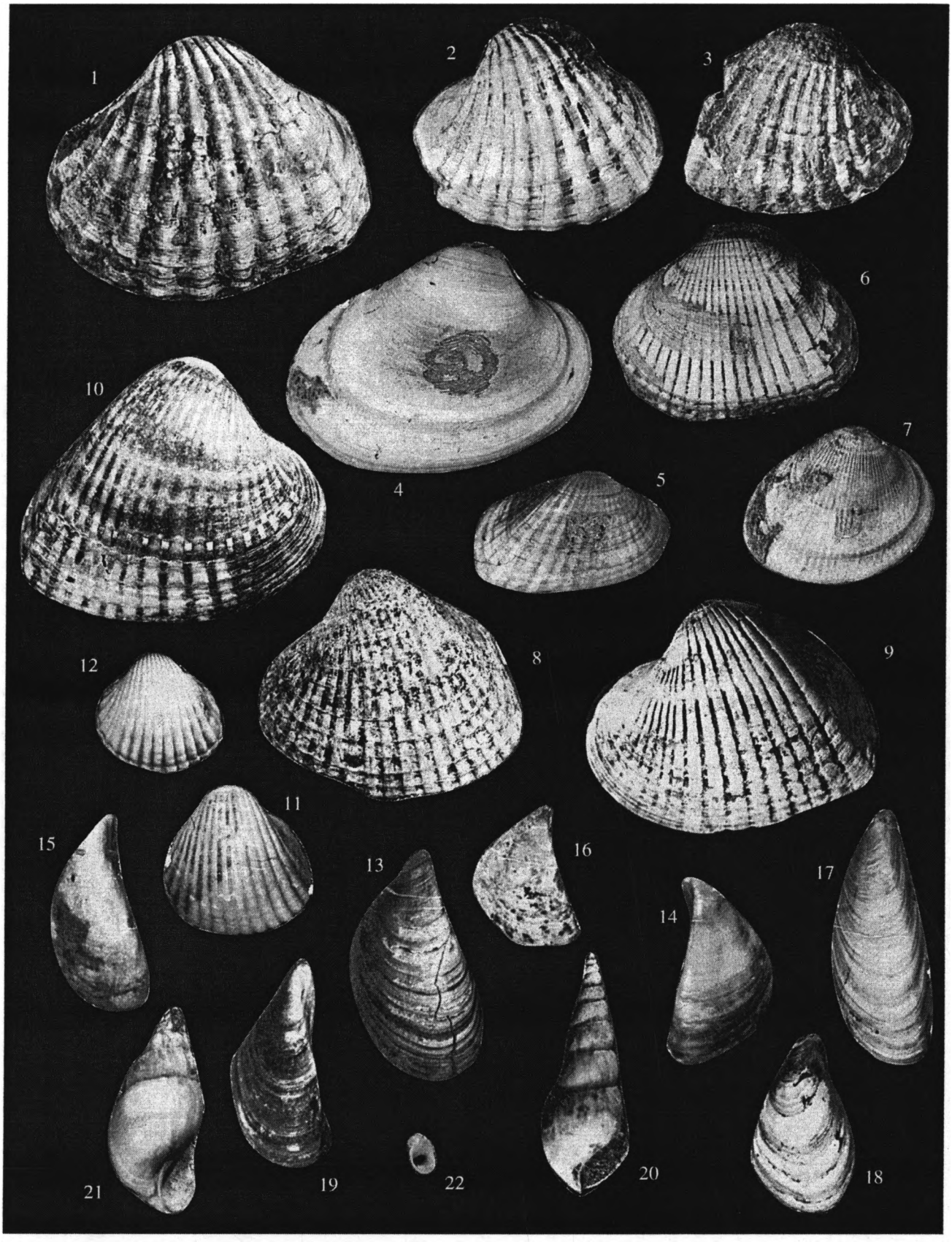


Fig. 2. Distribution of malacofauna throughout the Sangachal section: (1) limestone; (2) silt; (3) sand; (4) pebble; (5) molluscan shells; (6) abundant, (7) common, (8) rare, and (9) single shell specimens; (10) bed numbers and geological indices: ($Q_e^{ap_3}$) upper Apsheronian, ($Q_2^{hz_1}$) lower Khazarian; ($Q_3^{hv_2}$) upper Khvalynian, (Q_4^{nc}) Neocaspian.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poorly expressed interbeds and lenses. Dominants are *Dreissena* species of keel-free (*D. rostriformis* var. *distincta* Andrus.) and keeled (*D. polymorpha* Pall., *D. isseli* Andrus.) morphology. Also abundant are large shells of *Apscheronia propinqua* Eichw. Transition to overlying strata is gradual, showing a decrease in shell abundance. The apparent thickness is 2.2 m.

(2) Silt, dark gray, with less abundant molluscan shells. Dominants are small high-conical (*Micromelania subcaspia* Andrus.) and low-conical (*Clessiniola subvariabilis* Andrus.) gastropods. Less common are *Monodacna laevigata* Andrus., while *Hyrcania paucintermedia* (Andrus.) *H. intermedia* (Andrus.,) and *H. hyrcana* (Eichw.) are even rarer. Transition to overlying strata is gradual. The thickness is 1.5 m.

(3) Coquina, compact, with a silty gray and dark gray matrix. The molluscan assemblage consists mainly of keel-free and keeled *Dreissena* species. *Monodacna* and *Hyrcania* forms are also rather abundant, accompanied by *Apscheronia* forms. Transition to overlying sediments is distinct, marked by a sharp decrease in shell abundance. The thickness is 3 m.

(4) Silt, dark gray, compact, with ferruginate spots and rare large *Apscheronia* shells associated with diverse *Dreissena* and *Monodacna* species. Transition to overlying strata is distinct, though without a visible hiatus. The thickness is 0.5–1.0 m.

(5) Alternating organogenic limestone composed of *Dreissena* shell detritus and dark gray compact silt. The thickness is 1.5 m.

The high coastal part of the outlier of the late Khvalynian terrace is barren of the accumulative cover. Instead, only scattered large shells of the guide species *Didacna praetrigonoides* Nal. et Anis. and *Dreissena polymorpha* (Pall.) occur here. With the landward lowering of the terrace surface from 8–10 to 6–7 m, the Apsheronian rocks become overlain by the upper Khvalynian sediments (Fig. 2, Bed 7), the basal layer of which is composed of limestone blocks and dark-colored pebbles and grades into inequigranular bedded sands 1.5 m thick, which enclose gravel and pebble interbeds, and yield rare shells of *Didacna praetrigonoides* and *Dreissena polymorpha.*

In one of the sand quarry walls, there is a thin (0.2 m) bed of slightly lithified organogenic limestone with pebbles and rare shells of the early Khazarian (Gyurgyan) *Didacna subpyramidata* Prav., which separates the Apsheronian and upper Khvalynian rocks (Fig. 2, Bed 6).

The accumulative Neocaspian terrace situated southwest of the outlier of the Late Khvalynian abrasive terrace is composed of dark brown inequigranular locally ferruginate sands with abundant molluscan shells, among which *Cerastoderma glaucum* (=*Cardium edule*) Poir, *Didacna trigonoides* (Pall.), and *Dreissena polymorpha* (Pall.) are dominants (Fig. 2, Bed 8). The present-day sand beach (Fig. 2, Bed 9) contains abundant sells of *Cerastoderma glaucum, Didacna trigonoides, D. baeri* (Grimm.), *Theodoxus pallasi* L., *Dreissena polymorpha*, and *Mytilaster lineatus* (Gmel.).

Thus, the Sangachal section encloses sediments with diverse assemblages ranging in age from the Apsheronian to the Recent (Plate, Fig. 2). The Apsheronian and Pleistocene faunas lacking species in common (except for *Dreissena* forms) sharply differ from each other and are separated by a rather long time interval (early Pleistocene).

The Apsheronian molluscan assemblage includes forms characteristic of both the middle and upper substages. Nevertheless, taking into consideration the species composition of the Apsheronian malacofauna (Bogachev, 1932) and views of N.I. Andrusov, D.V. Golubyatnikov, and V.E. Ruzhentsev, one can conclude that many species are more characteristic of the late Apsheronian time rather than of the middle substage. These are *Apscheronia propinqua oblonga* (Eichw.), *Hyrcania intermedia* (Eichw.), *Plagiodacnopsis carinifera* (Andrus.), and *Dreissena rostriformis distincta* (Andrus.). Consequently, the host sediments can be referred to the upper Apsheronian. According to abundance rate and stratigraphic range of taxa, the molluscan fauna under consideration can be distinguished as the *Apscheronia propinqua oblonga–Hyrcania intermedia–Dreissena rostriformis distincta* assemblage.

The assemblage is uniform in general, and variations in its composition throughout the section reflect ecological parameters of sedimentation time: calm hydrodynamic conditions of a relatively deep sublittoral zone in a large brackish-water basin, where depo-

Plate. Mollusks from the Sangachal section:

(1) *Hyrcania intermedia* (Eichw.), upper Apsheronian, ×1.5; (2) *Hyrcania paucintermedia* (Andrus.), upper Apsheronian, ×1.5; (3) *Hyrcania hyrcana* (Andrus.), upper Apsheronian, ×1.5; (4) *Apscheronia propinqua oblonga* (Eichw.), upper Apsheronian, ×1.5; (5) *Monodacna laevigata* Andrus., upper Apsheronian, ×1.5; (6) *Monodacna* Andrus., upper Apsheronian, ×6; (7) *Plagiodacnopsis carinifera* (Andrus.), upper Apsheronian, ×2; (8) *Didacna subpyramidata* Prav., upper Khazarian, ×1.5; (9) *Didacna praetrigonoides* Nal. et Anis., upper Khvalynian, ×1; (10) *Didacna trigonoides* Pall., Neocaspian, ×1; (11) *Didacna baeri* (Grimm.), Recent, ×1.5; (12) *Cerastoderma glaucum* (Poir (=*Cardium edule*), Neocaspian, ×1.5; (13) *Cerastoderma glaucum* (Poir (=*Cardium edule*), Neocaspian, ×1.5; (14) *Dreissena polymorpha arnoldi* Andrus., upper Apsheronian, ×1.5; (15) *Dreissena polymorpha* (Pall.), Recent, ×1.5; (16) *Dreissena polymorpha* (Pall.), Neocaspian, ×1.5; (17) *Dreissena polymorpha* (Pall.), upper Khvalynian, ×1.5; (18) *Dreissena isseli* Andrus., upper Apsheronian, ×1.5; (19) *Dreissena rostriformis distincta* Andrus., upper Apsheronian, ×1.5; (20) *Mytilaster lineatus* (Gmel.), subfossil, ×1.5; (21) *Micromelania subcaspia* Andrus., upper Apsheronian, ×4; (22) *Clessiniola subvariabilis* Andrus., upper Apsheronian, ×4.

sition rate of fine-grained sediments was variable. The last factor intermittently suppressed and restricted development of benthic communities.

Several faunal subassemblages that characterize particular levels of the section and differ in abundance and composition of prevalent species can be conditionally outlined. These are the *Dreissena–Monodacna, Apscheronia–Micromelania, Dreissena–Monodacna–Plagiodacnopsis, Dreissena–Apscheronia*, and *Dreissena* subassemblages.

The Pleistocene fauna from the studied section is absolutely different, being less diverse, less abundant, and dominated by *Didacna* species. The *Didacna* genus is of a high species diversity, and different-age species can be distinguished in this case. These are the early Khazarian (Gyurgyan) *Didacna subpyramidata* Prav., late Khvalynian *Didacna praetrigonoides* Nal. et Anis., and Holocene *Didacna trigonoides* Pall.–*Didacna baeri* (Grimm.).

The described beds are easily recognizable in the section owing to appearance of Black Sea immigrants *Cerastoderma glaucum* Poir. in the Neocaspian deposits and of *Mytilaster lineatus* (Gmel.) in recent sediments. It should be noted that the late Khvalynian and Neocaspian faunal assemblages determine the age of host sequences and formation time of geomorphological elements, the low coastal terraces. For instance, the molluscan *Didacna praetrigonoides* assemblage implies that the vast low coastal plain in the study area is of the late Khvalynian age despite its low elevation above the Caspian Sea level (not more than 7–10 m). This controversy can be explained by neotectonic subsidence of this territory.

The diverse malacofauna allows the Sangachal section to be considered as the most complete succession of Eopleistocene–Pleistocene sediments in the Kobystan coast of the Caspian Sea. Nevertheless, for its more reliable subdivision, it is necessary to carry out additional investigations, paleomagnetic measurements inclusive, in both the considered area and Apsheronian Peninsula.

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